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MILLIMETER WAVE EXPERIMENT FOR ATS-F

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16. Abstract This document is the final technical report covering the development and production of a flight/prototype model of the Millimeter Wave Experiment to be included in the ATS-F spacecraft. Included is a brief description of the objectives of the experiment which are to investigate the propagation characteristics of the space to earth link at 20 and 30 GHz. Also included is a brief history of the contract covering the period from January 1970 to November 1972.

A detailed description of spaceborne equipment is provided. The equipment consists of two transmitters radiating signals at 20 and 30 GHz from either U.S. coverage horn antennas or a narrow beam parabolic antenna. Three modes of operation are provided: a continuous wave mode, a multitone mode in which nine spectral lines having 180 MHz separation and spaced symmetrically about each carrier, and a communications mode in which communications signals from the main spacecraft transponder are modulated on the two carriers.

Detailed performance attained in the flight/prototype model of the equipment is presented both under laboratory conditions and under environmental extremes. Provisions made for ensuring reliability in space operation are described. Also described in the report are the bench test equipment developed for use with the experiment and a summary of the new technology developed during the contract.

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1. INTRODUCTION

PURPOSE AND SCOPE

This report is the final technical report covering the development and production of a flight/prototype model of the millimeter wave experiment for ATS-F. It is submitted to satisfy the requirements of Item 19 and Article IIB of GSFC Contract NAS 5-21075. The purpose of the report is to describe the equipment and to record the performance that was attained in testing the flight/prototype model.

This section of the report includes the objectives of the millimeter wave experiment, a brief description of the experiment hardware, and a brief chronological history of the contract. Included in subsequent sections of the report are more detailed descriptions and performance achieved at the system and unit level, a summary of the qualification testing of the experiment, some salient quality assurance aspects of the program, a description of the bench test equipment for the experiment, and a summary of the new technology developments.

EXPERIMENT OBJECTIVES

General

The primary objectives of the ATS-F millimeter wave experiment are to provide characteristics of the synchronous satellite to earth (space-earth) propagation channels at 20 and 30 GHz. These data are inputs to a definitive analysis to evaluate the usefulness of millimeter wave frequencies for communications and scientific data link applications. The time variant physical characteristics of the atmosphere at these frequencies are investigated by observing the disturbances introduced on test waveforms and wideband communications signals.

Objectives

The ATS-F millimeter wave experiment empirical data will be used to:

1) Provide propagation characteristics of space-earth links at 20 and 30 GHz under defined meteorological conditions, which include:

   a) Attenuation

   b) Phase statistics

   c) Coherence bandwidth

   d) Site diversity improvement

2) Provide engineering data on space-earth communications links operating at 20 and 30 GHz under various meteorological conditions and modulation techniques, which will include:

   a) Carrier to noise

   b) Modulation index

   c) Bit error rate

   d) Information rate

   e) 20, 30, and 4 GHz comparisons

3) Establish a model for the prediction of millimeter wave propagation effects, which will include:

   a) Radiometric sky temperature

   b) Rainfall rate

   c) Radar backscatter

   d) Channel time-frequency covariance functions

To achieve the stated objectives, the empirical data obtained from the millimeter wave experiment will be analyzed using three general areas of investigation identified as propagation data analysis, communications link analysis, and channel correlation analysis; each is defined in following paragraphs.

Propagation Data Analysis

The propagation data analysis includes accumulation and cumulative comparison of signal effects versus meteorological data such as rainfall rate, weather radar return, radiometer temperature, wind velocity and direction, temperature, barometric pressure, and refractive index. These propagation data are used to generate statistical models which can be applied to the evaluation of millimeter wave communications link performance. Daily, weekly, monthly, seasonal, and annual statistics are generated for each NASA participating station by a computer program which includes presentations of cumulative distribution of attenuation and relative phase, correlation of attenuation and radiometer sky temperature, radar return, rain rate, and other statistical variables.

Communications Link Analysis

The communications experiment is implemented by transmission of modulated test signals on 20 or 30 GHz downlinks, either separately or simultaneously. The test signals are obtained by IF cross-strapping to the ATS-F communications transponder system. An additional benefit derived from the cross-strapped transponder configuration is the ability to directly compare operating millimeter wave communications with the relatively well defined 4 GHz downlink. The comparison permits the evaluation of the millimeter wave channel with well defined performance parameters under identical meteorological and satellite link conditions.

Channel Correlation Analysis

The channel correlation analysis is a study of channel characterization by two-dimensional correlation measurements on the signal data. This investigation includes an evaluation of important channel parameters such as coherence bandwidth, time spread, fading bandwidth, and coherence time. The channel characteristics are determined by a direct measurement approach which involves the determination of the first and second order statistics (correlation function) of the propagation channel transfer function for various meteorological conditions. This is accomplished using the transmitted multitone test waveform to generate the autocorrelation and crosscorrelation of the received carrier envelopes. These data are used in developing an estimation of the two-dimensional (time-frequency) channel covariance function.

EXPERIMENT DESCRIPTION SUMMARY

The millimeter wave experiment equipment to be mounted in the ATS-F spacecraft consists of two transmitters, one radiating at 20 GHz and the other at 30 GHz. For two of the three operating modes, all of the elements comprising the transmitters have backup redundant elements which may be switched in by command. For the third mode (communications) no redundancy is provided for some of the system elements. The equipment is divided into four major units: the RF multiplier, the 20/30 GHz modulator/power amplifier, the 20/30 GHz horn antenna assembly, and the 20/30 GHz parabolic antenna, all of which are located in the earth viewing module of the

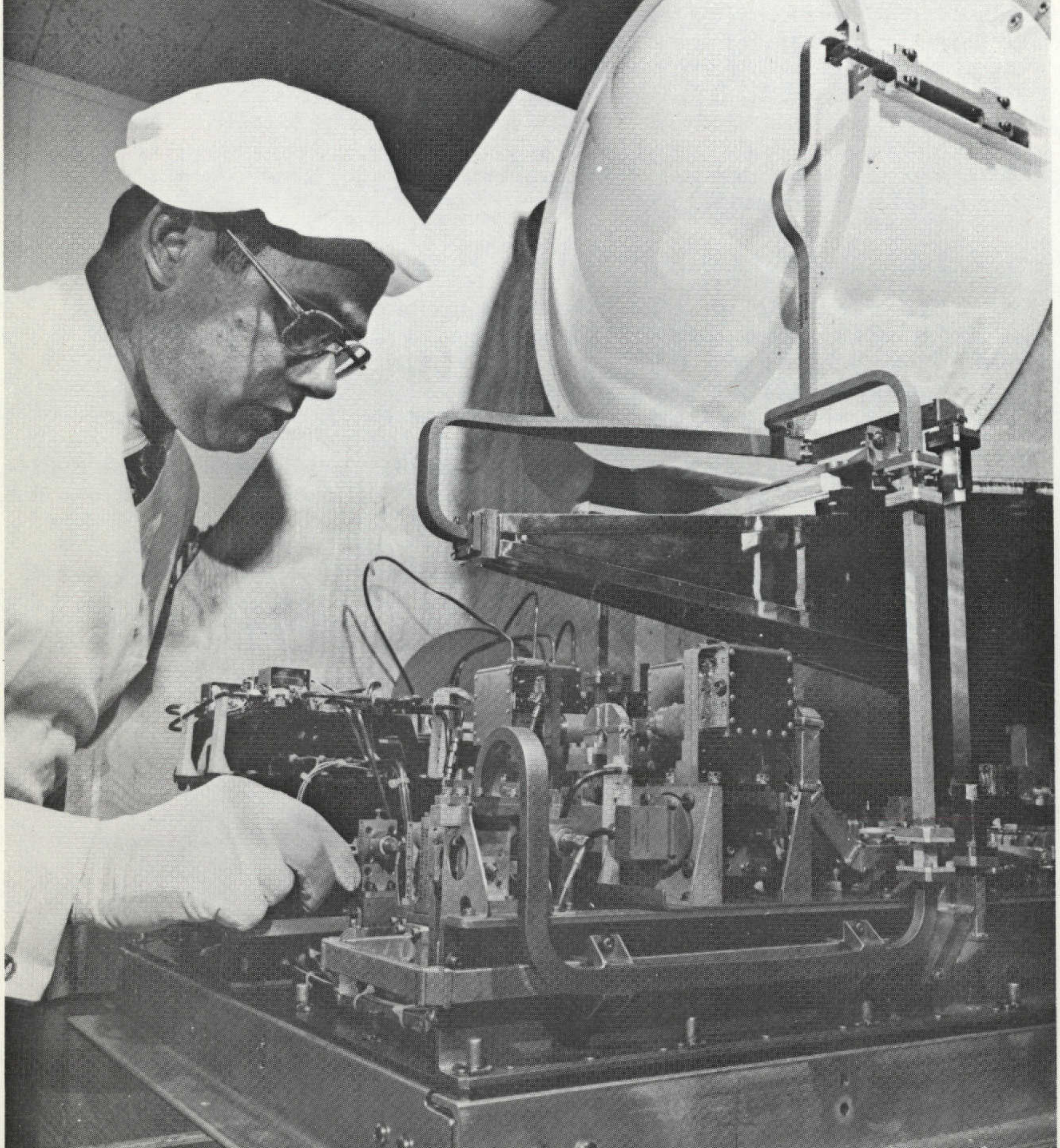


FIGURE 1-1. EXPERIMENT MOUNTED ON MOCKUP SIMULATING SPACECRAFT INSTALLATION (PHOTO 4S09085)

spacecraft. The equipment weighs slightly more than 90 pounds and requires approximately 70 watts of power from the spacecraft bus. A photograph of the experiment on a frame somewhat simulating the spacecraft installation is shown in Figure 1-1.

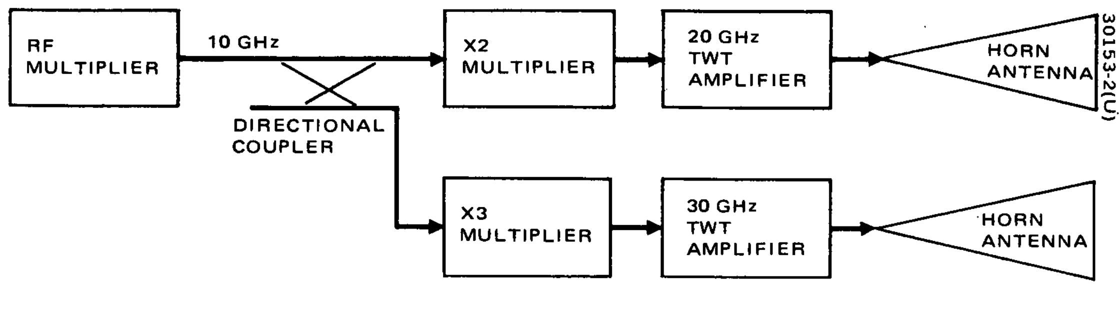
Modes of Operation

The experiment is commandable into three modes of operation: a continuous wave mode in which the 20 and 30 GHz carriers only are transmitted; a multitone mode in which nine spectral lines spaced 180 MHz apart and centered at 20 GHz and at 30 GHz are transmitted; and a communications mode in which the FM communications signals received on the spacecraft transponder are retransmitted at 20.15 and 30.15 GHz.

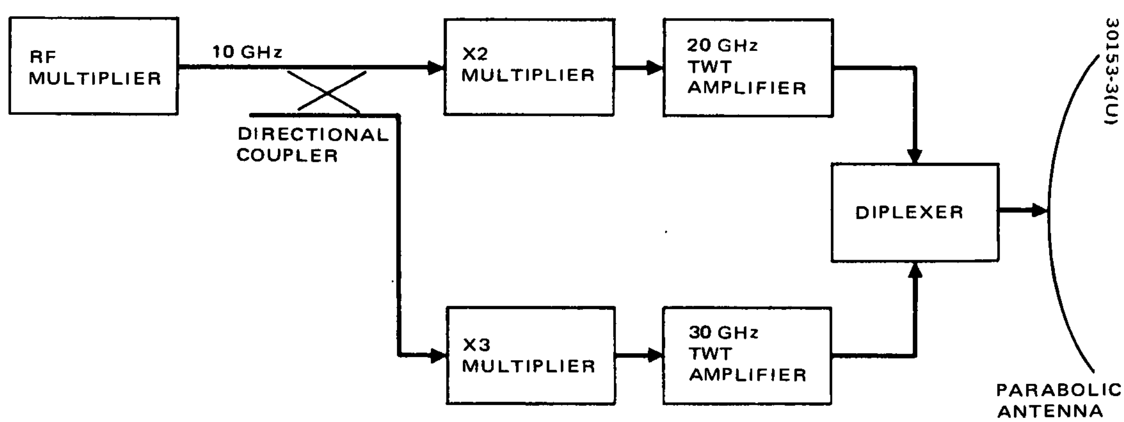
Simplified block diagrams of the experiment configuration for the CW mode are shown in Figure 1-2 for the cases of radiation from the horn antennas and the parabolic antenna, respectively. In each case a 10 GHz signal is generated in the RF multiplier which uses a very stable 5 MHz crystal oscillator as a reference. The 10 GHz signal is applied to X2 and X3 frequency multipliers and the resulting 20 and 30 GHz signals are amplified by TWTAs for radiation by the antennas.

Simplified block diagrams of the experiment configuration for the multitone mode are shown in Figure 1-3 for the cases of horn antennas and parabolic antenna, respectively. In this mode a 180 MHz modulating signal is derived from the same 5 MHz master oscillator as the 10 GHz. The 180 MHz signal drives the phase modulators at 10 GHz and the modulated signal is frequency multiplied X2 and X3 to achieve multitone spectrums at 20 and 30 GHz as shown in the spectrum analyzer photographs (Figure 1-4). The 20 and 30 GHz multitone signals are amplified by traveling-wave tube amplifiers (TWTAs) for radiation by the antennas.

The configuration of the experiment for the communications mode is shown in simplified form in Figure 1-5. In this mode the 10 GHz signal is again frequency multiplied to 20 and 30 GHz as in the CW mode, and these two frequencies are used to pump two upconverters. Signal drive for the upconverters consists of the frequency modulated 150 MHz IF signal from the spacecraft transponder suitably amplified by an IF amplifier. The resulting 20.15 and 30.15 GHz FM signals are then amplified by TWTAs for radiation by the parabolic antenna. An alternative configuration is available in which the 150 MHz FM signal is generated in a voltage controlled oscillator where the modulating signal is the communications baseband signal from the spacecraft transponder.

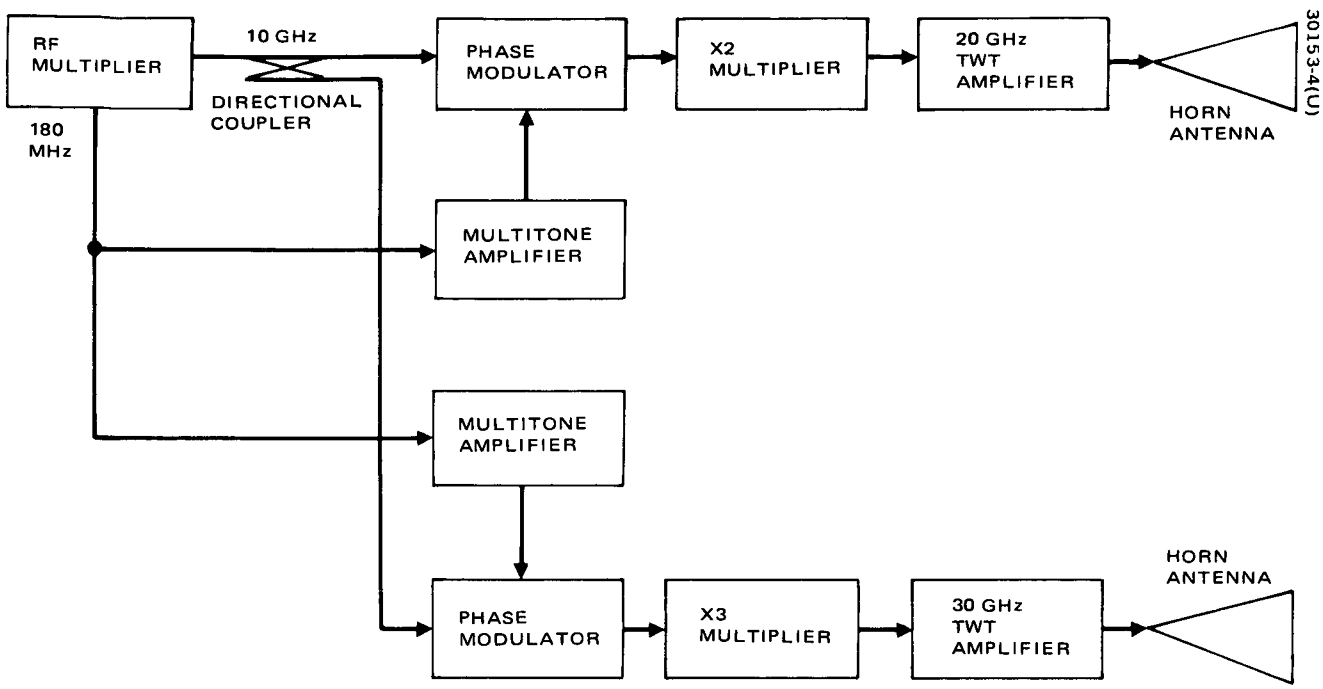


a) USING HORN ANTENNAS

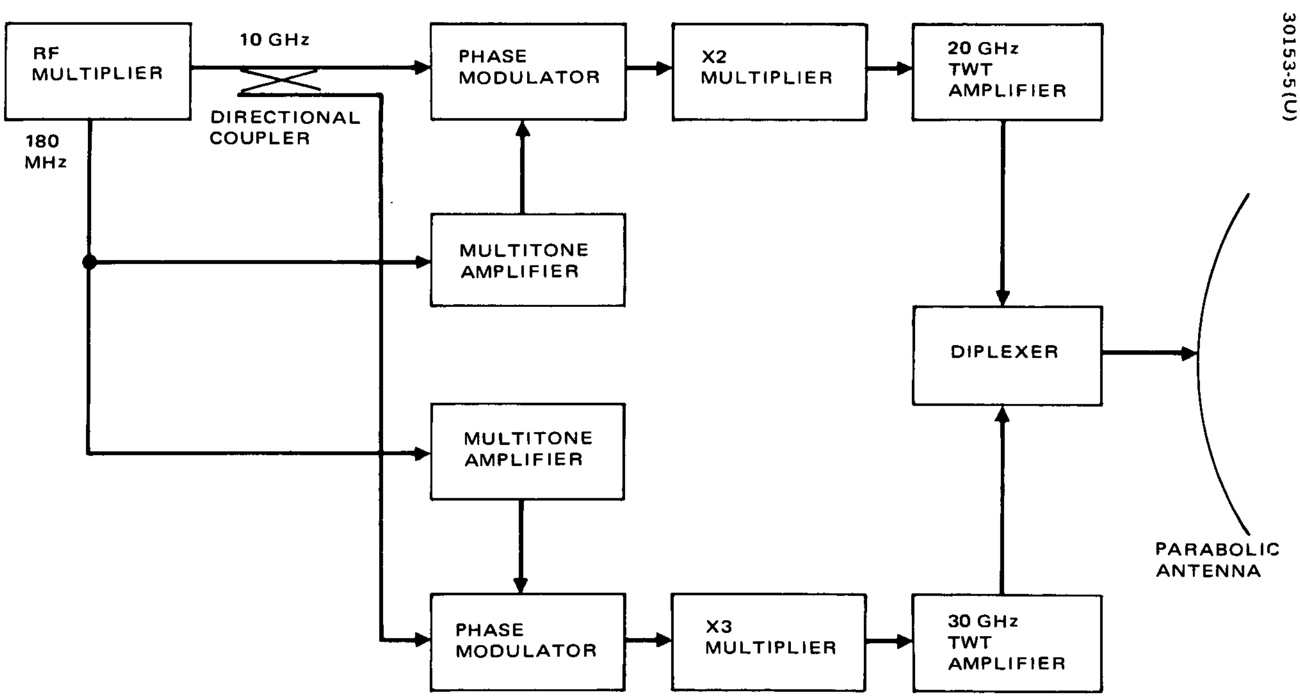


b) USING PARABOLIC ANTENNA

FIGURE 1-2. CW MODE SIMPLIFIED BLOCK DIAGRAM

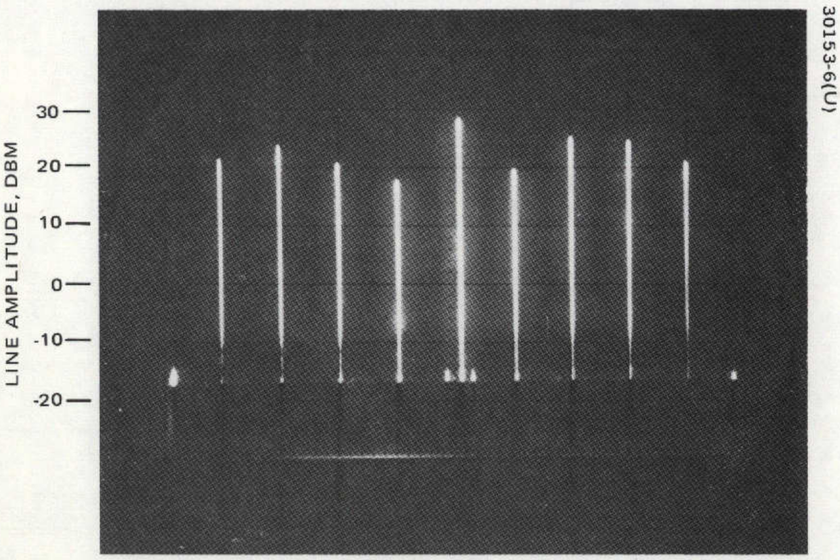


a) USING HORN ANTENNAS



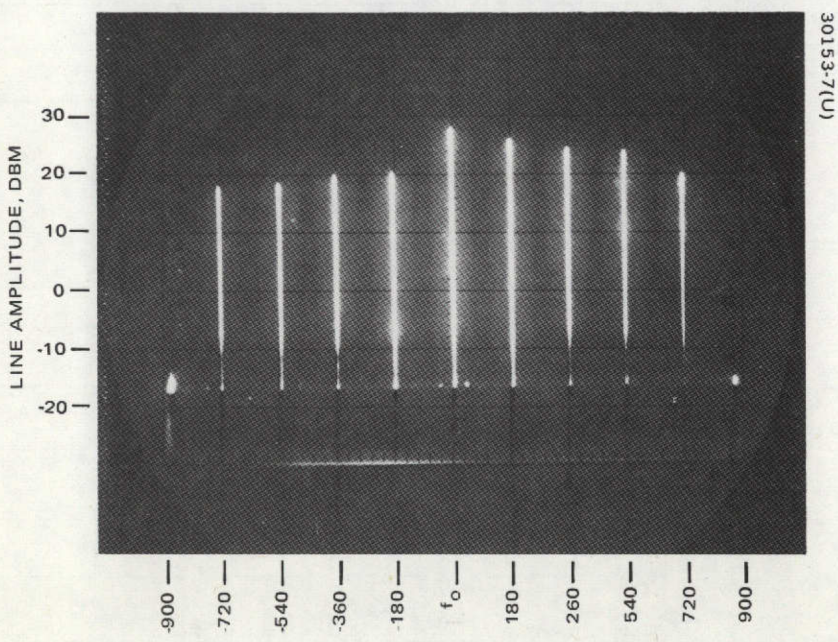
b) USING PARABOLIC ANTENNA

FIGURE 1-3. MULTITONE MODE SIMPLIFIED BLOCK DIAGRAM



FREQUENCY, MHZ

a) 20 GHz



FREQUENCY, MHZ

b) 30 GHz

FIGURE 1-4. MULTITONE MODE SPECTRA AT TWTA OUTPUT

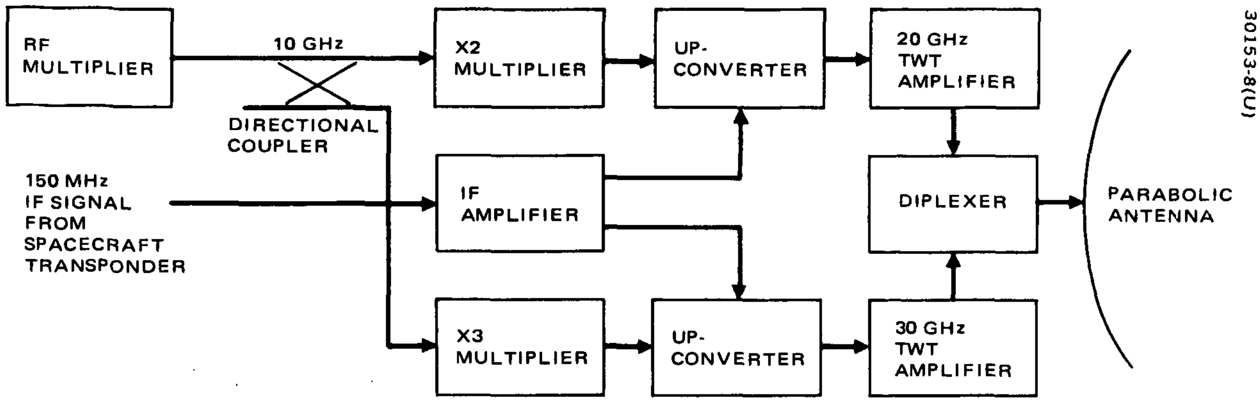


FIGURE 1-5. COMMUNICATIONS MODE SIMPLIFIED BLOCK DIAGRAM

Propagation

Three antennas are provided in the experiment: a 20 GHz horn antenna, a 30 GHz horn antenna, and a 20/30 GHz parabolic antenna. In each case the radiated RF is linearly polarized with the plane of the E-vector aligned to the north-south axis of the spacecraft. For both horn antennas the 3 dB bandwidths are approximately 6 degrees in the north-south direction and approximately 8 degrees in the east-west direction. Assuming a spacecraft location at 95 degrees west longitude and the earth pointing axis directed at Topeka, Kansas, the coverage of the horn antennas (3 dB) will be as shown by the ellipse in Figure 1-6. The parabolic antenna provides a 3 dB beam-width of approximately 2.3 degrees at 20 GHz and approximately 1.6 degrees at 30 GHz. With the spacecraft earth pointing axis directed at Rosman, North Carolina, coverage of the parabolic antenna (3 dB) will be as shown by the two circles in Figure 1-6. Based on measured performance of the experiment hardware, the effective isotropic radiated power (EIRP) of the antennas at the peak of the beam will be as listed in Table 1-1.

CONTRACT HISTORY

This subsection summarizes in narrative form the significant events in the technical history of the millimeter wave experiment contract. Important milestones and technical changes to the contract are described in the general chronological order of occurrence.

The initial phase of the program consisted of two activities: preliminary development work on the 20 and 30 GHz traveling-wave tubes and a design study to define the subsystem configuration. The TWT development work started in October 1969, and the design study commenced with the start of the formal contract in early January 1970. Initially the design study was to occur in the first 3 months of 1970 but it was extended to the middle of May 1970 to provide for better interface definition between the experiment and the ATS-F spacecraft. The design study culminated in a design study

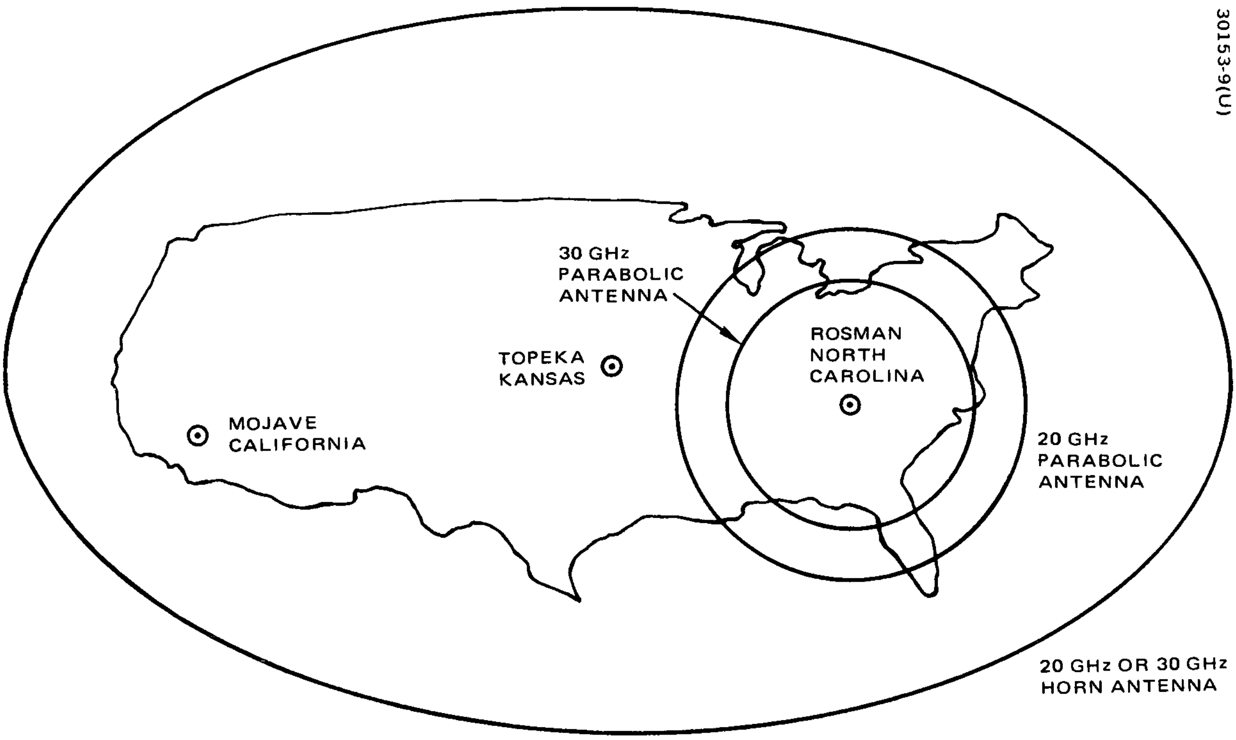


FIGURE 1-6. COVERAGE OF MILLIMETER WAVE EXPERIMENT ANTENNAS (SPACECRAFT LOCATION 95° WEST LONGITUDE)

report published in May 1970 and a conceptual design review held in early June 1970. At the conclusion of this effort, the full scale development work began.

During the design study phase, it was decided that the most desirable way of cross-strapping the communications signals from the transponder was at the 150 MHz intermediate frequency. However, there was concern that the additional routing of the 150 MHz IF might cause interference problems in the

TABLE 1-1. EIRP AT ANTENNA BEAM MAXIMUM

Antenna	EIRP, dBm	
	20 GHz	30 GHz
Horn		
CW mode	61.0	59.8
Multitone mode	60.1	59.9
Communications mode	60.3	60.1
Parabolic		
CW mode	70.3	73.6
Multitone mode	70.2	73.8
Communications mode	71.3	73.3

spacecraft. It was therefore decided that the experiment should contain provisions for accepting either IF or baseband signals from the transponder and that the decision as to which would be used would be made at spacecraft integration. Contractual coverage for this added provision was contained in Contract Modification No. 4 executed in July 1970.

It was also determined during the design study that the horn antennas would have insufficient gain to propagate a useful communications mode signal. It was therefore agreed that two of the four horn antennas (one at each frequency) would be replaced by an 18 inch parabolic antenna with diplexing to carry both frequencies on the one antenna. Contractual coverage for the change in antenna configuration was contained in Contract Modification No. 5 executed in August 1970.

At the conceptual design review, concern was expressed over the lack of spares for the TWT amplifiers which, because of the many processing steps involved in their manufacture, are very long lead time items. In the event of a TWTA failure serious schedule problems could result if the manufacture of a replacement had to start from scratch. It was therefore agreed that one spare TWT and associated power supply should be built for each of the two frequencies. Contractual coverage for these additional TWTAs was contained in Contract Modification No. 8 executed in November 1970.

Late in September 1970, the second of the four contractually required design reviews was held. Detailed physical and electrical interfaces were described, performance parameters as demonstrated by breadboard hardware tests were presented, and various quality assurance topics were discussed. Comment sheets from the GSFC review committee were subsequently forwarded from the ATS-F and G project office for action, clarification, or comment.

Early in October 1970, an announcement was made that a new contractor was selected for the development of the ATS-F and G spacecraft. This resulted in a series of iterations of the physical design of the experiment. Minor modifications were required in the RF multiplier and somewhat more extensive changes were needed in the modulator/power amplifier, but very extensive changes had to be made in the antennas and unfortunately the antenna designs were at that time the most mature of any of the units. The detailed efforts required to implement the interface changes were covered in Contract Modification No. 16 executed in October 1971. Additional interface changes were subsequently required and the effort to implement these was covered in Contract Modification No. 24 executed in July 1972.

Late in February 1971, the third of the contractually required design reviews was held. The review board consisted of Hughes and GSFC personnel and the primary topic of the review was the detailed product design of all of the experiment hardware.

At the February design review, it was learned that there would be a requirement for a combined thermal and structural model of the experiment rather than a thermal model as defined in the Contract Specification. The more sophisticated requirements of the thermal/structural model lead to additional design and fabrication efforts and these efforts were covered in Contract Modification No. 9 and 13, the latter of which was executed in July 1971.

During the summer and fall of 1971, the qualification tests were completed on several significant elements of the experiment. The horn antennas completed their tests in July 1971, and the parabolic antenna tests were completed in August 1971. In each case the thermal cover underwent the qualification testing in conjunction with its associated antenna. Qualification tests of the Model 268H TWT (20 GHz) and the Model 254H TWT (30 GHz) were completed in August and November 1971, respectively.

In April 1971, it was learned that there would be a COMSAT experiment on board the ATS-F spacecraft which would have receivers at 12 and 18 GHz. Since the multitone mode of the millimeter wave experiment could have spectral lines that could cause interference to the higher frequency COMSAT receiver, it was decided that high pass filters should be incorporated into the experiment. Contractual coverage for these added filters was contained in Contract Modification No. 14 executed in August 1971.

A significant milestone was achieved in September 1971 when the thermal/structural model of the experiment was delivered to the spacecraft contractor's facility. This model was then successfully integrated into the thermal/structural model spacecraft through the joint efforts of personnel from Hughes and the spacecraft contractor.

From quite early in the contract it had been known that there was an ATS-F program office requirement for measuring the electromagnetic interference (EMI) characteristics of the experiment. No EMI limits were to be imposed as acceptance criteria but the data would be supplied for analysis by the program office. Contractual coverage for the added EMI tests was contained in Contract Modification No. 22 executed in April 1972.

Formal qualification tests on the electronic subsystem of the experiment began in late 1971 and continued sporadically with the final test being completed in July 1972. The tests included mass properties determination, ambient conditions performance tests, storage temperature tests, operating temperature tests, vibration tests, thermal vacuum tests, and EMI tests. Also included near the end of the test sequence was a compatibility test between the experiment and the companion ground receiver built by another contractor. Contractual coverage for this latter test was contained in Contract Modification No. 26 executed in November 1972.

The final design review required by the contract was held in August 1972. The primary purpose of this meeting was to review in depth the various quality assurance aspects of the experiment and on the basis of the review to give consent to Hughes to ship the experiment flight/prototype model to the spacecraft contractor. Shipment of the experiment occurred in November 1972.

2. SYSTEM DESCRIPTION AND PERFORMANCE

INTRODUCTION

This section describes the operation of the complete experiment and presents the system performance achieved in the flight/prototype model. The system performs exceptionally well and will provide RF signals which should satisfy the experiment objectives. This section includes functional descriptions of the experiment system, RF output signal performance in various modes, command features, telemetry outputs, dc power configuration and performance, and a description of significant physical aspects of the system.

BLOCK DIAGRAM DESCRIPTION

The complete block diagram of the millimeter wave experiment is illustrated in Figure 2-1. The diagram shows the separation of the system into four units: 1) the RF multiplier which serves as the basic source of the RF drive energy; 2) the 20/30 GHz modulator/power amplifier which accomplishes the modulation of the RF signals, performs the final frequency multiplication, and provides the final power amplification of the 20 and 30 GHz output signals; 3) the 20 and 30 GHz horn antennas which radiate U. S. coverage signals from one each of the 20 and 30 GHz power amplifiers; and 4) the 20/30 GHz parabolic antenna which radiates narrow beam signals from one each of the 20 and 30 GHz power amplifiers. The block diagram also shows the extent of redundancy in the system, i.e., redundant master oscillators, redundant multiplier chains, redundant modulation chains for the multitone mode, redundant power amplifiers, but non-redundant modulation chains for the communications mode.

The basic frequency reference of the experiment is a 5 MHz crystal controlled oscillator housed in a temperature controlled oven. After the temperature of the oven has stabilized at the operating point of about 160°F, the frequency of the oscillator is within ±10 Hz of the nominal 5 MHz, and the short term stability is better than two parts in 10^{10} averaged over 10 ms. Long term drift of the oscillator is expected to be better than one part in 10^7 per year.

The 5 MHz signal from the oscillator is amplified in a buffer amplifier and the resulting power is directed to both redundant multiplier chains by a power splitter. The first step in each multiplier chain is a X8 multiplier module which consists of three transistor X2 multipliers in tandem. Two outputs are brought out of the module: the 20 MHz signal resulting from the first two X2 multipliers and a 40 MHz signal which is the result of the last X2 multiplier.

The 20 MHz signal is applied to the X9 multiplier module which consists of two transistor X3 multipliers in tandem. The resulting 180 MHz signal which has a level of about 10 mw is available as an output of the RF multiplier unit. It is then connected to the 20/30 GHz modulator/power amplifier unit as the VHF signal used to provide the multitone modulation.

The 40 MHz signal out of the X8 multiplier is applied to the X10 module where it is multiplied to 400 MHz by means of a single step varactor diode multiplier. The 400 MHz signal is then amplified in the 400 MHz power amplifier module to a level of about 1.25 watts. Further multiplication to 2 GHz is accomplished by a step recovery diode X5 multiplier. Amplification of the 2 GHz signal to a level of 2.4 watts is performed by the 2 GHz power amplifier module which uses an MSC 3003 microwave power transistor. Final multiplication to 10 GHz occurs in the X5 multiplier module which uses a Philco-Ford L8513 step recovery diode. The resulting 10 GHz signal is available at the output of the RF multiplier unit at a level of about 500 mw. It is then connected to the 20/30 GHz modulator/power amplifier unit for modulation and multiplication to the final 20 and 30 GHz signals.

When the experiment is commanded to the multitone mode, the 10 GHz signal from the RF multiplier unit is directed through a coaxial circulator switch to the multitone/continuous wave group of the modulator/power amplifier unit. Here the 10 GHz power is divided in a 6 dB directional coupler. The straight through signal is attenuated by 2 dB and applied to the 30 GHz phase modulator module, and the 6 dB down signal is applied directly to the 20 GHz phase modulator. At the same time the 180 MHz signal from the RF multiplier is amplified in the multitone amplifiers and applied to the modulation input of the phase modulators. The 10 GHz signals which have been phase modulated by the 180 MHz signals are then frequency multiplied by the X2 multiplier module for the 20 GHz output and by the X3 multiplier module for the 30 GHz output. The resulting 20 and 30 GHz signals are then passed through waveguide circulator switches (which select the A or the B continuous wave/multitone group) and through level setting adjustable attenuators to the power summing 3 dB hybrids. For the CW mode, the action is the same except that the multitone amplifiers are turned off and consequently no modulating 180 MHz signal is applied to the phase modulators.

When the experiment is commanded to the communications mode, the 10 GHz signal from the RF multiplier unit is directed through the coaxial circulator switch to the communications group of the modulator/power

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amplifier unit. After passing through another coaxial circulator switch (which selects the A or B multiplier chain), the 10 GHz power is divided by a 6 dB directional coupler. The straight through signal is applied to the X3 multiplier module, and the 6 dB down signal is applied to the X2 multiplier module. The resulting 30 GHz and 20 GHz signals are applied to the pump ports of the 20 and 20 GHz upconverter modules, respectively. At the same time 150 MHz IF signals from the IF amplifier module are applied to the IF ports of both upconverters. The upper sideband from each upconverter, i.e., 20.15 and 30.15 GHz, is fed to the power summing 3 dB hybrid. In the baseline configuration the 150 MHz IF input signal to the IF amplifier comes directly from the IF processor of the spacecraft transponder. Alternatively, the IF signal may be derived from the VCO module where the frequency modulation on the 150 MHz signal is controlled by baseband signals from the demodulator of the spacecraft transponder.

In all modes, the 20 or 30 GHz signals out of the 3 dB hybrids are passed through level setting adjustable attenuators to the inputs of the 20 and 30 GHz traveling-wave tube amplifiers (TWTAs). The TWTAs (only one of which at each frequency is on at one time) provide approximately 42 dB of gain to give a saturated RF output power of over 2 watts. The output of each TWTA is monitored by a power monitor whose dc output is fed into the telemetry subsystem. In the case of the TWTAs associated with the parabolic antenna, the 20 and 30 GHz signals are combined in a diplexer so that the outputs are in a common waveguide. The RF outputs, then, of the modulator/power amplifier unit are carried in three waveguides: one 20 GHz WR42 waveguide, one 30 GHz WR28 waveguide, and one 20/30 GHz WR34 waveguide.

The 20 GHz signals in the WR42 waveguide pass through a high pass filter to the 20 GHz horn antenna. The purpose of the filter, which is basically a section of reduced width guide, is to stop radiations which might affect the COMSAT 17.8 GHz receiver. The 20 GHz horn antenna, which is a truncated square pyramid, has a gain of approximately 27 dB with a north-south 3 dB beamwidth of about 6 degrees and an east-west 3 dB beamwidth of about 8 degrees. The 30 GHz signals in the WR28 waveguide are fed directly to the 30 GHz horn antenna which has essentially the same characteristics at 30 GHz as the 20 GHz horn antenna has at 20 GHz.

The 20 and 30 GHz signals in the WR34 waveguide pass through a high pass filter to the parabolic antenna. The filter has essentially the same characteristics and the same purpose as the one in the 20 GHz horn antenna waveguide. The parabolic antenna consists of a parabolic reflector recessed in a cylindrical tunnel with a scalar feed mounted at the prime focus of the parabola. At 20 GHz, the antenna has a gain of about 37 dB and a 3 dB beamwidth of about 2.3 degrees. At 30 GHz, its gain is about 39 dB and beamwidth about 1.6 degrees.

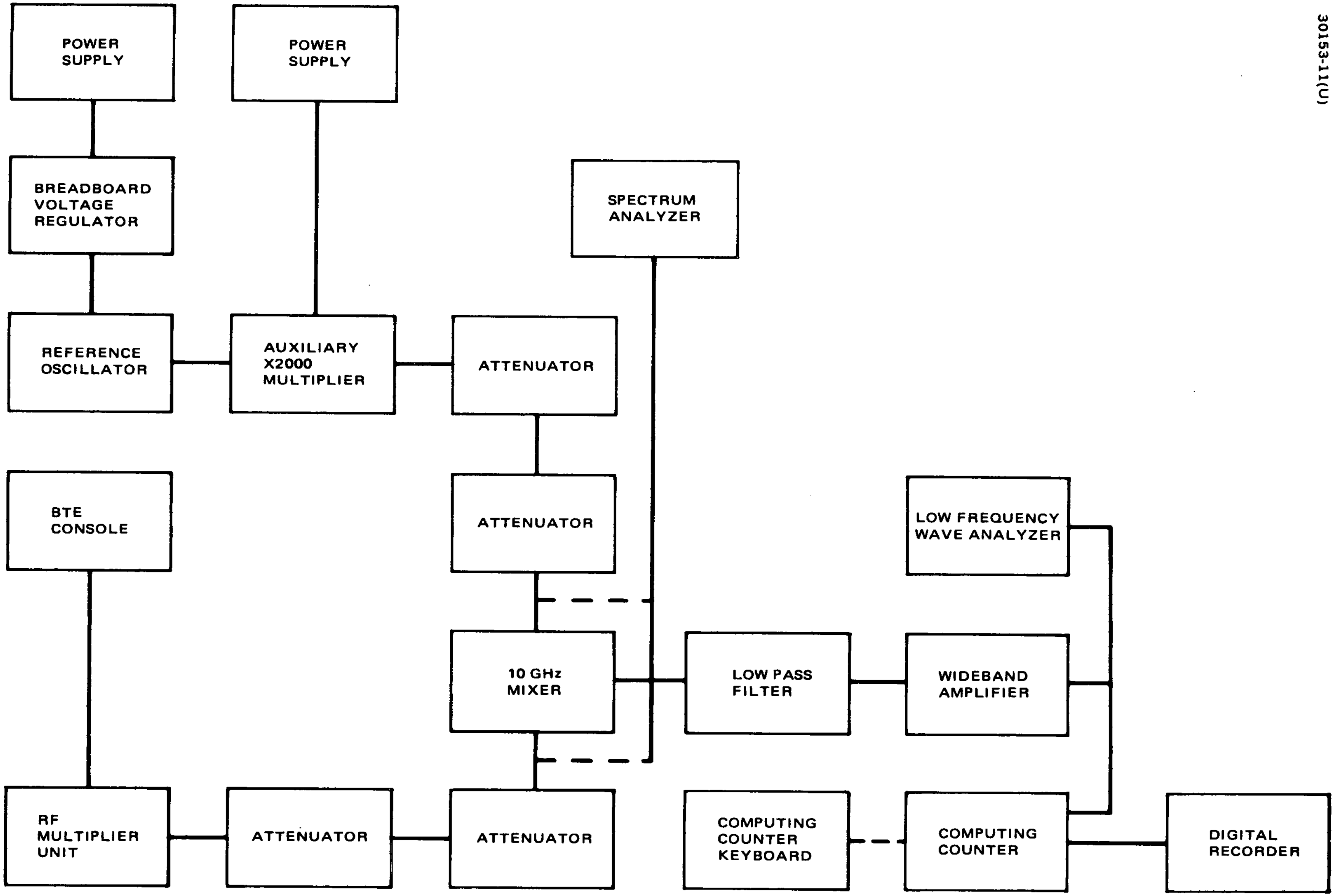

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FIGURE 2-2. TEST SETUP FOR MEASURING FREQUENCY STABILITY AND SPECTRAL PURITY

RF PERFORMANCE IN VARIOUS MODES

There are three basic modes in which the experiment can operate, continuous wave, multitone, or communications. In addition, there are redundant master oscillators, redundant multiplier chains, and redundant TWTAs. Therefore, for each RF output frequency, 24 different combinations of equipment may be selected. Which master oscillator is selected has no effect on the RF performance except in frequency stability and spectral purity. Conversely, except for the communications mode, the modules other than the master oscillator have no effect on frequency stability and little or no effect on spectral purity. Therefore the discussion in this section will be grouped under four topics, one concerned with frequency and spectral purity and three concerned with other RF characteristics in the three basic modes.

Frequency Stability and Spectral Purity

For the continuous wave and multitone modes the short term frequency stability and spectral purity was measured on the 10 GHz signal out of the RF multiplier unit. The test setup used is shown in Figure 2-2 and the reference oscillator used was the qualification model master oscillator followed by the breadboard model X2000 multiplier chain. Thus the results obtained are a combination of the effects of the flight hardware and the test reference oscillator and one can infer that each contributes about half of the total effect.

For the short term CW frequency stability test, the fractional frequency deviation method was employed (References 2-1 and 2-2) utilizing the Hewlett-Packard 5360A computing counter and the Hewlett-Packard 5375A keyboard. Measuring time was set for 10 ms, and computation was done for 10 sets of 100 samples each. The best and worst case computations of the 10 sets is given in Table 2-1 along with the actual frequency difference between the 10 GHz output and the frequency of the reference oscillator chain. Data is given in Table 2-1 for all combinations of master oscillators and multiplier chains and at three temperatures corresponding to room ambient and high and low qualification levels.

For the CW spectral purity test, a Sierra 301B low frequency wave analyzer was used with a 3 dB bandwidth of about 10 Hz, and the difference frequency between the 10 GHz output and the reference oscillator was approximately 12 kHz. The level of noise output at four frequencies away from the difference frequency is given in Table 2-2 corrected to a 1 Hz bandwidth. Again data is given in Table 2-2 for all combinations of master oscillators and multiplier chains and at three temperatures.

It should again be noted that for both the fractional frequency deviation and spectral purity tests the results quoted are for a combination of the two oscillators and therefore the actual performance of one is better than shown.

TABLE 2-1. FRACTIONAL FREQUENCY DEVIATION OF CARRIER OVER TEMPERATURE

		-10°C Temperature			25°C Temperature			50° Temperature		
Master Oscillator	Multiplier Chain	Worst Case* Fractional Frequency Deviation, parts/10^{10}	Best Case** Fractional Frequency Deviation, parts/10^{10}	Frequency Difference Between Oscillators, kHz	Worst Case* Fractional Frequency Deviation, parts/10^{10}	Best Case** Fractional Frequency Deviation, parts/10^{10}	Frequency Difference Between Oscillators, kHz	Worst Case* Fractional Frequency Deviation, parts/10^{10}	Best Case** Fractional Frequency Deviation, parts/10^{10}	Frequency Difference Between Oscillators, kHz
A	A	1.98	1.54	11.347	1.77	1.54	11.584	1.78	1.46	11.804
A	B	2.46	2.06	11.349	2.24	1.66	11.579	1.8	1.51	11.804
B	A	1.88	1.64	11.373	1.52	1.18	11.759	1.85	1.46	12.091
B	B	2.35	1.57	11.377	1.6	1.29	11.763	2.0	1.51	12.096

*Worst case = greatest fractional frequency deviation computed out of 10 sets, each set having 100 samples of 10 ms each.
**Best case = least fractional frequency deviation computed from the same 10 sets.

TABLE 2-2. SPECTRAL PURITY OF CARRIER OVER TEMPERATURE

		Noise Level Below Carrier in 1 Hz Bandwidth at Indicated Frequency Away From Carrier, dB											
		-10°C				25°C				50°C			
Master Oscillator	Multiplier Chain	20 Hz	100 Hz	1 kHz	15 kHz	20 Hz	100 Hz	1 kHz	15 kHz	20 Hz	100 Hz	1 kHz	15 kHz
A	A	-37.5	-34.5	-71.5	-73.5	-41.5	-54.5	-73.5	-75.5	-37.5	-54.5	-75.5	-77.5
A	B	-37.0	-48.5	-81.5	-94.5	-38.5	-33.5	-73.5	-76.5	-39.5	-45.5	-76.5	-77.5
B	A	-41.5	-72.5	-73.5	-74.5	-42.5	-58.5	-76.5	-75.5	-41.5	-56.5	-75.5	-78.5
B	B	-48.5	-60.5	-73.5	-73.5	-41.5	-37.5	-75.5	-75.5	-38.5	-37.5	-78.5	-68.5

Long term stability of the CW and multitone modes can only be inferred from data accumulated on the TACSAT which uses identical master oscillators. The frequency readings obtained from the user of this satellite in orbit show some scatter but a definite downward trend. Over a period of 16 months the maximum change in frequency was 3.6 parts in 10^8 including worst case measurement error and maximum scatter.

For the communications mode the frequency stability and spectral purity is primarily a function of the 150 MHz signal since the 10 GHz source in the experiment provides higher stability than can be expected from a VCO and very probably much better than the spacecraft transponder IF. No assessment can be made of the communications mode parameters when the spacecraft IF is used as the 150 MHz signal. However, short term stability of the VCO has been measured and the results are shown in Table 2-3. Long term drift of the VCO center frequency may be as much as 1 MHz.

CW Mode RF Output Power

Since the experiment outputs in the CW mode consist of a continuous carrier at 20 GHz and at 30 GHz, the characteristic of importance is the total radiated power. Table 2-4 shows the RF output power of each of the TWTAs with each of the redundant multiplier chains at room ambient temperature, at the low acceptance test temperature (+5 °C), and at the high acceptance test temperature (+35 °C) measured at the output ports of the modulator/power amplifier unit. To obtain the effective radiated power, the peak gain of each antenna must be known as well as the measured value of the RF power into each antenna at center frequency, both of which are also listed in Table 2-4.

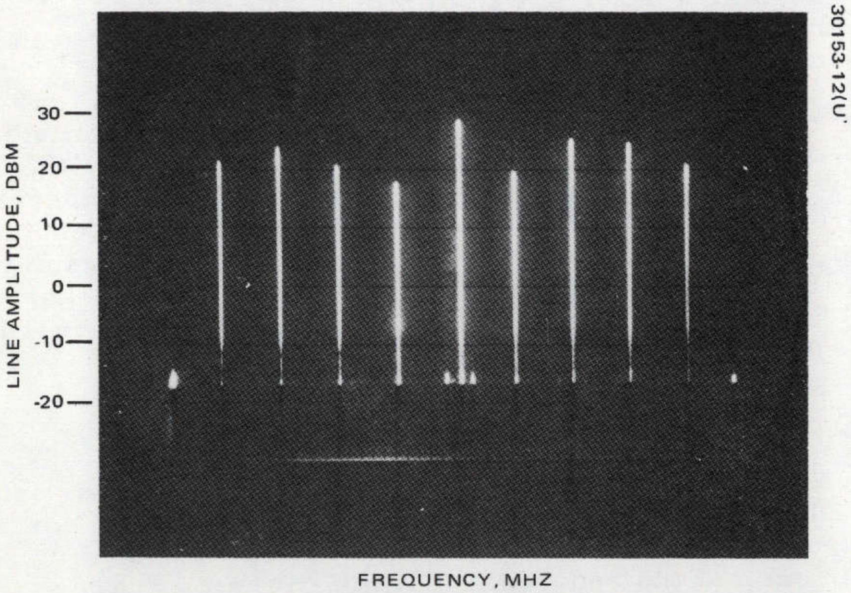
Multitone Mode RF Output Signal

The experiment outputs in the multitone mode consist of signals at 20 and 30 GHz which are made up of nine spectral lines spaced 180 MHz apart with four lines below the carrier and four lines above the carrier. Typical spectrum analyzer displays of the signals at 20 and 30 GHz are shown

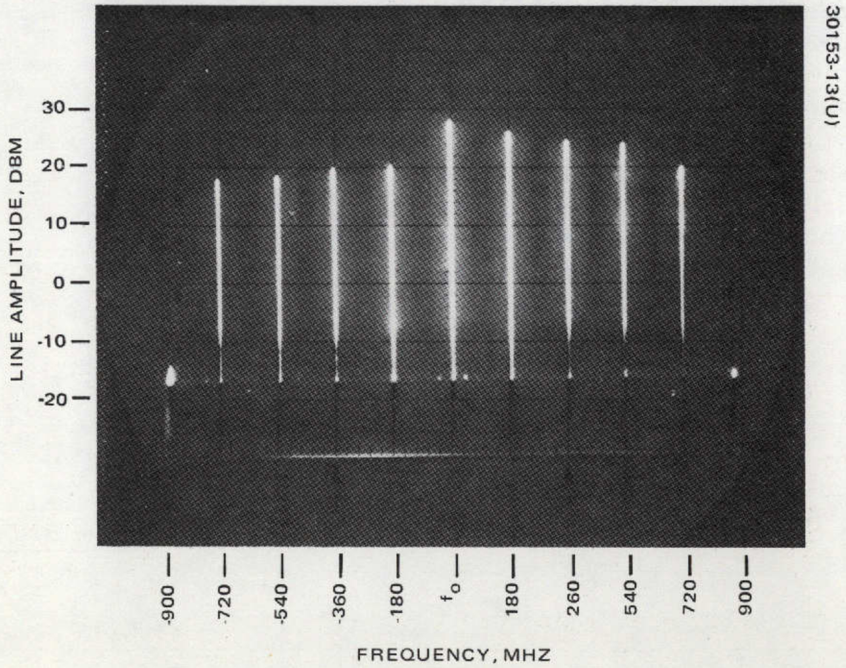
TABLE 2-3. FRACTIONAL FREQUENCY DEVIATION OF VOLTAGE CONTROLLED OSCILLATOR

Worst Case* Fractional Frequency Deviation, parts/10^7	Best Case** Fractional Frequency Deviation, parts/10^7
1.62	1.24

*Worst case = greatest fractional frequency deviation computed out of 10 sets, each set having 100 samples of 10 ms each.
**Best case = least fractional frequency deviation computed from the same 10 sets.



a) 20 GHz



b) 30 GHz

FIGURE 2-3. MULTITONE MODE SPECTRA AT TRAVELING-WAVE TUBE AMPLIFIER OUTPUT

TABLE 2-4. CW MODE RF OUTPUT POWER

Multiplier Chain	TWTA*	TWTA Output, dBm +5°C	TWTA Output, dBm +25°C	TWTA Output, dBm +35°C	Antenna Input, dBm +25°C	Antenna Gain, dB
A	20 HA	33.82	33.84	33.66	33.27	27.8
B	20 HA	33.72	33.75	33.56	33.12	
A	20 PA	32.18	32.85	33.05	32.79	37.6
B	20 PA	32.07	32.72	32.90	32.66	
A	30 HA	32.66	32.64	32.46	32.40	27.4
B	30 HA	32.94	32.85	32.52	32.40	
A	30 PA	33.37	33.65	33.39	33.42	40.1
B	30 PA	33.86	33.91	33.55	33.55	

*20 HA indicates 20 GHz TWTA connected to horn antenna.
20 PA indicates 20 GHz TWTA connected to parabolic antenna.
30 HA indicates 30 GHz TWTA connected to horn antenna.
30 PA indicates 30 GHz TWTA connected to parabolic antenna.

in Figure 2-3. The multitone spectra are generated by phase modulating the 10 GHz signal from the RF multiplier with the 180 MHz signal, also from the RF multiplier. Two different modulation indices are used in two separate phase modulators. The signal from one phase modulator drives a X2 frequency multiplier, the result being the modulated 20 GHz signal, and the signal from the second phase modulator is multiplied by three to produce the modulated 30 GHz signal.

The objective of the modulating process was to generate signals in which all nine spectral lines have equal magnitudes and in which the magnitude of all spectral lines outside the nine is insignificant. At the same time the modulated signal should have no amplitude modulation so that the AM to PM conversion effect of the saturated TWTAs will not cause serious perturbations in the spectrum. Although this condition can be closely approximated in theory, the best result achieved in practice gave a dispersion of the desired spectral line magnitudes of about 5 dB (not including the center line which was approximately 4 dB above the average of the other eight lines). The combination of system elements which gave the worst result had about 7 dB dispersion (again not including the center line which was about 7 dB above the average of the other eight). Spectral lines beyond the desired nine decreased very rapidly in magnitude at successive line locations away from the carrier; for example, the ±5 lines were about 5 dB below the average of the nine and the ±6 lines were about 8 dB below.

It should be noted that having higher power in the center line, as parenthetically stated above, does not detract from the experiment objectives. In fact, under some circumstances it may be desirable for best operation of the ground receivers.

Although not quite as significant as individual magnitudes of spectral lines, the 20 and 30 GHz total RF output powers for the different configurations and temperatures are given in Table 2-5 in the same way as for the CW mode. In this table the antenna gains given are an approximate average over the bands of interest. Also presented in Table 2-5 is the measured value of total RF power into each antenna at center frequency.

TABLE 2-5. MULTITONE MODE RF OUTPUT POWER

Multiplier Chain	TWTA*	TWTA Output, dBm			Antenna Input, dBm	Antenna Gain, dB
		+5°C	+25°C	+35°C	+25°C	
A	20 HA	33.39	33.39	33.23	32.82	27.3
B	20 HA	33.45	33.42	33.24	32.82	
A	20 PA	32.27	32.69	32.80	32.73	37.5
B	20 PA	32.40	32.74	32.76	32.73	
A	30 HA	33.24	33.15	32.98	32.67	27.3
B	30 HA	33.22	33.12	32.97	32.59	
A	30 PA	33.77	33.71	33.52	33.68	40.3
B	30 PA	33.69	33.65	33.40	33.49	

*20 HA indicates 20 GHz TWTA connected to horn antenna.
20 PA indicates 20 GHz TWTA connected to parabolic antenna.
30 HA indicates 30 GHz TWTA connected to horn antenna.
30 PA indicates 30 GHz TWTA connected to parabolic antenna.

More important than the total output power is the magnitude and stability of the spectral lines. The objective was to have no spectral line of less than 60 mw (17. 8 dBm) as measured at the input to the antennas. A precision measurement of the magnitude of each line was made using a cavity wavemeter set to filter out all but the line being measured. The results of the measurements for various experiment configurations and over the acceptance temperature range are given in Table 2-6.

TABLE 2-6. MULTITONE MODE SPECTRAL LINE MAGNITUDES

Multiplier Chain	TWTA*	Temperature, °C	Spectral Line Power at Antenna Input, dBm								
			-4	-3	-2	-1	f_o	+1	+2	+3	+4
		+5	18.1	19.0	20.5	25.8	25.4	24.3	24.3	23.1	19.6
A	20 HA	+25	19.9	21.6	22.0	19.6	27.4	25.5	24.2	23.2	18.9
		+35	18.9	21.7	22.2	21.2	27.2	26.2	24.4	23.2	18.5
		+5	18.9	20.2	21.1	20.0	25.3	23.5	25.9	24.3	20.2
B	20 HA	+25	20.9	22.2	22.8	19.6	27.2	23.0	25.4	24.1	19.6
		+35	18.3	22.1	22.6	22.1	27.1	23.3	24.5	24.3	19.5
		+5	18.2	19.1	20.5	20.4	25.6	25.0	24.0	22.9	19.3
A	20 PA	+25	18.9	19.2	20.3	20.1	26.7	24.9	23.7	23.4	19.5
		+35	18.9	19.5	20.6	20.6	26.7	25.6	24.0	23.2	19.0
		+5	19.0	20.2	21.1	20.0	25.2	23.0	25.6	24.0	19.9
B	20 PA	+25	19.7	19.0	21.0	20.4	26.1	21.9	24.9	24.7	20.2
		+35	19.8	20.6	20.9	20.3	26.3	22.9	25.1	24.5	20.0
		+5	21.5	22.7	20.8	18.2	26.5	19.3	24.2	24.5	21.1
A	30 HA	+25	21.2	22.8	20.8	18.7	26.3	20.1	24.1	24.1	20.6
		+35	20.6	23.0	21.3	18.4	26.0	20.4	24.4	23.4	19.6
		+5	21.9	21.6	18.6	20.5	25.0	19.0	23.8	25.8	22.3
B	30 HA	+25	21.8	22.0	18.8	20.5	24.9	18.8	23.9	25.4	21.5
		+35	21.6	22.5	18.9	20.1	25.0	18.2	23.8	24.8	21.0
		+5	21.3	24.0	21.3	18.5	28.0	20.4	25.2	24.8	21.9
A	30 PA	+25	21.0	23.7	21.5	19.1	27.9	21.1	24.9	24.5	21.4
		+35	20.3	23.1	21.9	18.5	27.2	21.4	25.2	24.4	20.7
		+5	21.8	22.7	19.0	21.3	26.7	20.4	24.6	26.0	23.0
B	30 PA	+25	21.8	22.9	19.3	21.1	26.7	20.4	24.6	25.8	22.4
		+35	21.2	22.4	19.6	20.3	26.3	19.7	24.3	25.6	22.3

*HA indicates TWTA connected to horn antenna.
PA indicates TWTA connected to parabolic antenna.

Because of the presence of COMSAT receivers on board the ATS-F spacecraft, there was concern that the 20 GHz multitone spectrum which exists below the desired -4 line would interfere with one of these receivers. For this reason high pass filters were placed between the 20 GHz TWTAs and the antennas. With the filters in place the spectral content of the RF output signals in the region of the COMSAT receiver frequency was measured and the results are given in Table 2-7.

Communications Mode RF Output Signals

In the communications mode the experiment has two options with regard to the input modulating signal, one of which will be selected and wired in permanently prior to launch. The first and preferred option utilizes the 150 MHz, frequency modulated, IF signal from the spacecraft transponder directly which will be supplied to the experiment at a level of -3 dBm. The IF signal is amplified and upconverted to 20. 15 and 30. 15 GHz.

The other less preferred option utilizes the baseband communication signal from the spacecraft transponder which would be supplied to the experiment at a level of 1. 0 volt peak-to-peak. The signal frequency modulates the 150 MHz center frequency of the experiment VCO, and after amplification the 150 MHz signal is upconverted to 20. 15 and 30. 15 GHz.

The 30 GHz RF output power in the communications mode was subjected to more variations over temperature than were the other two modes. This was a result of less drive power to the TWTA due to high conversion losses that were present in the 30 GHz upconverter and also a result of lower gain in the 30 GHz TWTAs than in the 20 GHz TWTAs. The 20 and 30 GHz RF output power in the communications mode for the different configurations and temperatures are given in Table 2-8 for a constant unmodulated 150 MHz IF input signal at -3 dBm. Table 2-9 gives the variation in communications mode RF output power as a function of the level of unmodulated 150 MHz IF input signal.

TABLE 2-7. MULTITONE MODE RF POWER AT ANTENNA INPUTS AT COMSAT RECEIVER FREQUENCIES

Multiplier Chain	TWTA	Spectral Line Power at Antenna Input, dBm -13 17.66 GHz	-12 17.84 GHz
A	20 HA	<-117	<-109
B	20 HA	<-116	<-108
A	20 PA	<-131	<-130
B	20 PA	<-123	<-122

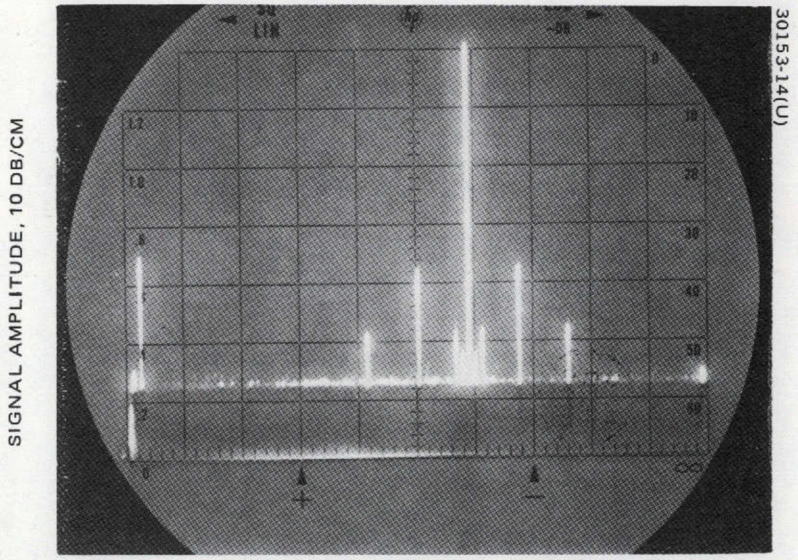
TABLE 2-8. COMMUNICATION MODE RF OUTPUT POWER, UNMODULATED
(CONSTANT AMPLITUDE IF INPUT)

Multiplier Chain	TWTA*	TWTA Output, dBm +5°C	TWTA Output, dBm +25°C	TWTA Output, dBm +35°C	Antenna Input, dBm 25°C	Antenna Gain, dB
A	20 HA	33.56	33.84	33.37	33.00	27.3
B	20 HA	33.56	33.75	33.38	33.00	
A	20 PA	33.70	33.81	33.75	33.66	37.6
B	20 PA	33.72	33.85	33.75	33.68	
A	30 HA	33.30	32.64	32.62	32.68	27.4
B	30 HA	33.30	32.85	32.58	32.63	
A	30 PA	33.61	33.35	33.15	33.20	40.1
B	30 PA	33.59	33.24	33.12	33.30	

*20 HA indicates 20 GHz TWTA connected to horn antenna.
20 PA indicates 20 GHz TWTA connected to parabolic antenna.
30 HA indicates 30 GHz TWTA connected to horn antenna.
30 PA indicates 30 GHz TWTA connected to parabolic antenna.

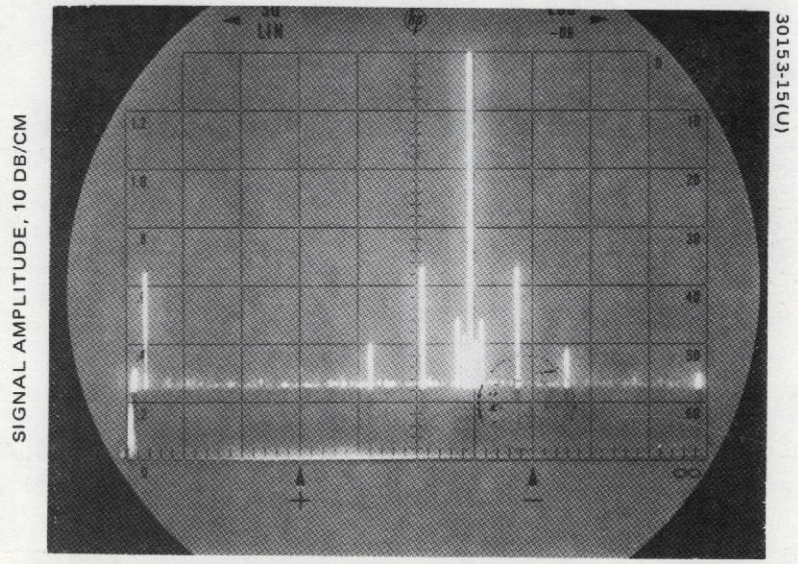
TABLE 2-9. COMMUNICATION MODE RF OUTPUT POWER, UNMODULATED
(FUNCTION OF IF INPUT LEVEL USING MULTIPLIER CHAIN A)

TWTA	TWTA Output at Indicated IF Input Level, dBm -6 dBm	-5 dBm	-4 dBm	-3 dBm	-2 dBm	-1 dBm
20 PA	33.79	33.74	33.70	33.75	33.78	33.84
30 PA	33.29	33.35	33.40	33.40	33.39	33.40



FREQUENCY, 0.18 GHZ/CM

a) 20 GHz



FREQUENCY, 0.18 GHZ/CM

b) 30 GHz

FIGURE 2-4. COMMUNICATIONS MODE SPECTRA AT TRAVELING-WAVE TUBE AMPLIFIER OUTPUT (UNMODULATED)

In the configuration option which uses the 150 MHz IF input, the RF output power as a function of the actual IF frequency (bandpass characteristic) is given in Table 2-10 for the 20 and 30 GHz outputs. Frequency deviation characteristics when using the VCO (baseband input) were measured and found to be +7.5 ± 0.75 MHz for a 1 volt peak-to-peak baseband signal.

The output spectra when using an unmodulated IF input are shown in the spectrum analyzer photographs of Figure 2-4. It can be seen that the magnitude of the spurs on either side of the 20.15 and 30.15 GHz carriers are at least 30 dB below the carriers. For the case of baseband input (10 kHz, 1 volt peak-to-peak, sine wave), the output spectra are shown in the photographs of Figure 2-5. Again the spurs, which are not shown on these two expanded displays, are at least 30 dB down.

Because of test equipment limitations, certain additional communications parameters were not measured on a complete experiment, but rather on the IF amplifier alone or a combination of the VCO and IF amplifier. A baseband frequency response test was performed on the combination VCO/IF amplifier and the results are given in Table 2-11. Video intermodulation distortion tests were performed on the combination VCO/IF, and IF intermodulation distortion tests were performed on the IF amplifier alone. The results are shown on Figures 2-6 and 2-7, respectively. Group delay measurements were made on the combination VCO/IF amplifier and the results are shown on the photograph of the Hewlett-Packard link analyzer display (Figure 2-8).

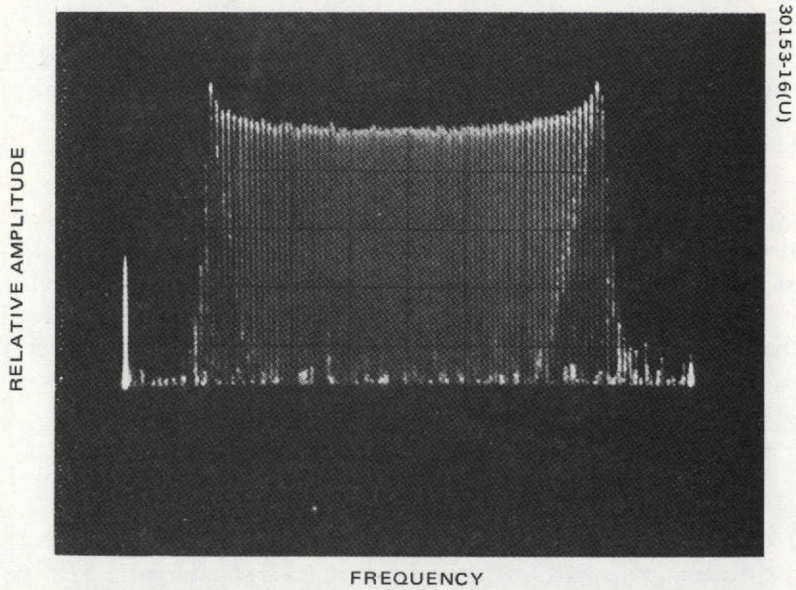
COMMAND

The millimeter wave experiment is controlled in orbit by a set of 22 commands. The ON/OFF control is provided, a selection of redundancy configurations is made, and selection of operating mode is accomplished by sending the appropriate commands to the spacecraft from the ground station.

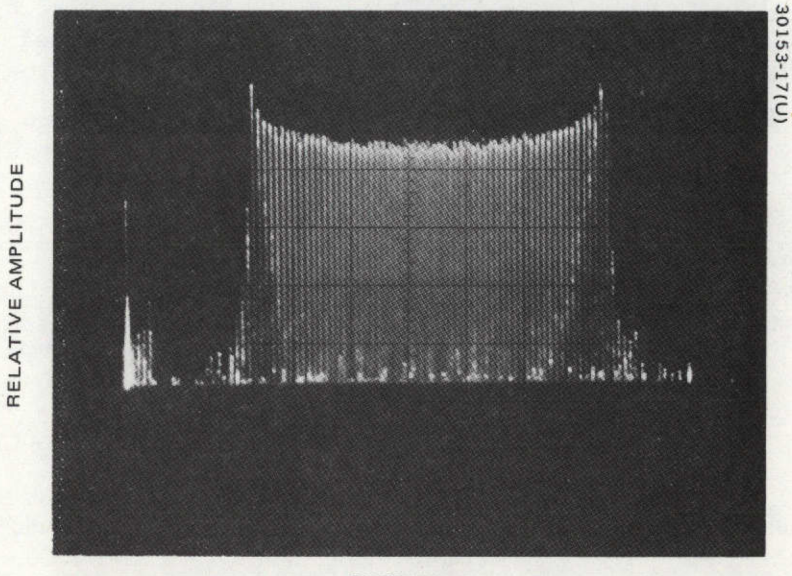
TABLE 2-10. COMMUNICATION MODE BANDPASS CHARACTERISTICS

IF Frequency,* MHz	20 Parabolic Antenna TWTA Output Power, dBm	30 Parabolic Antenna TWTA Output Power, dBm
130.0	33.48	33.39
137.5	33.50	33.19
150.0	33.72	33.39
162.5	33.65	33.40
170.0	33.71	33.42

*IF drive level held constant at -3 dBm.



a) AT 20 GHz



b) AT 30 GHz

FIGURE 2-5. COMMUNICATIONS MODE SPECTRA AT TRAVELING-WAVE TUBE OUTPUT, MODULATED

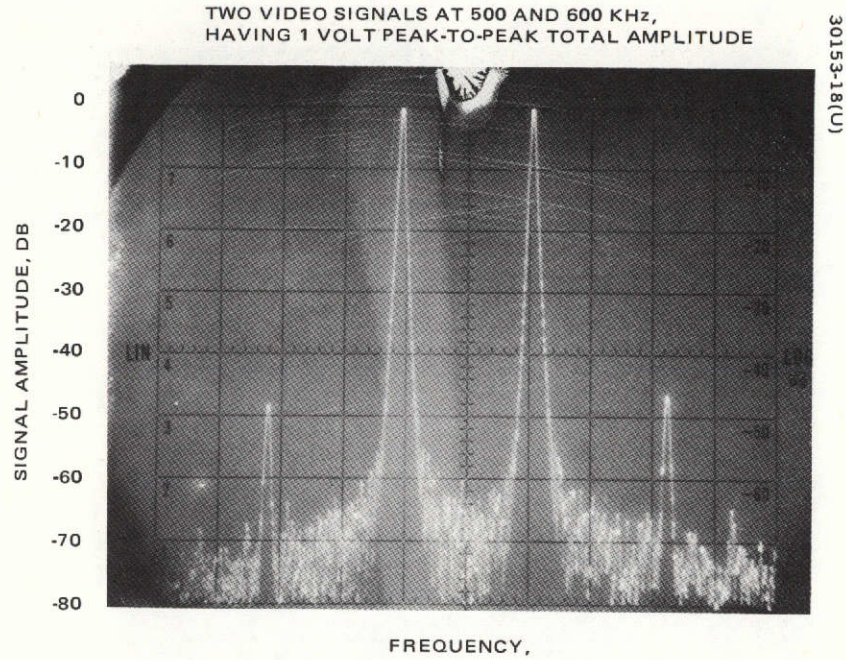


FIGURE 2-6. VCO/IF AMPLIFIER COMBINATION INTERMODULATION DISTORTION TEST

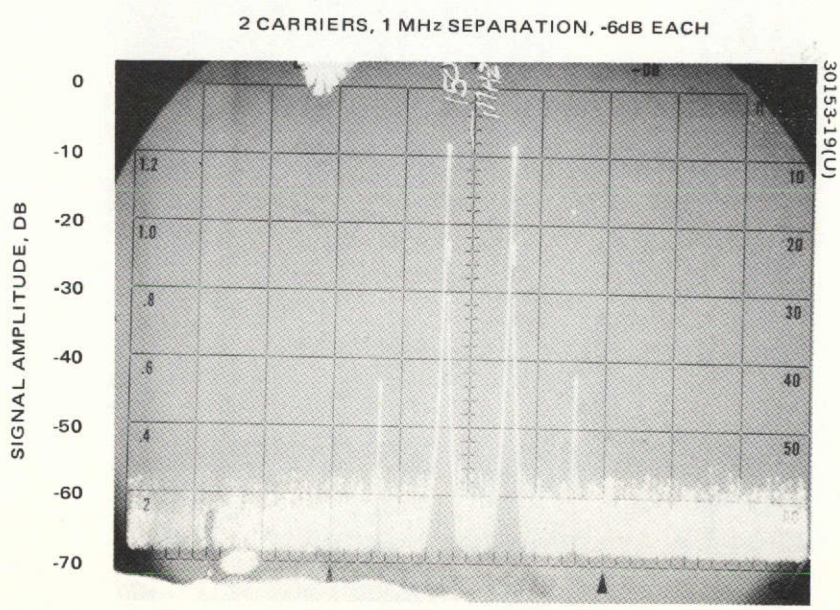
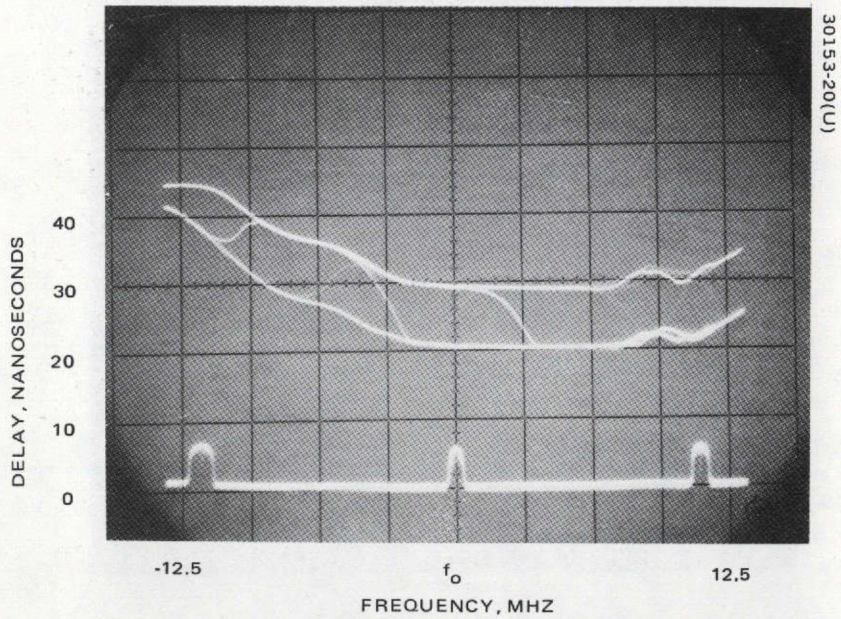
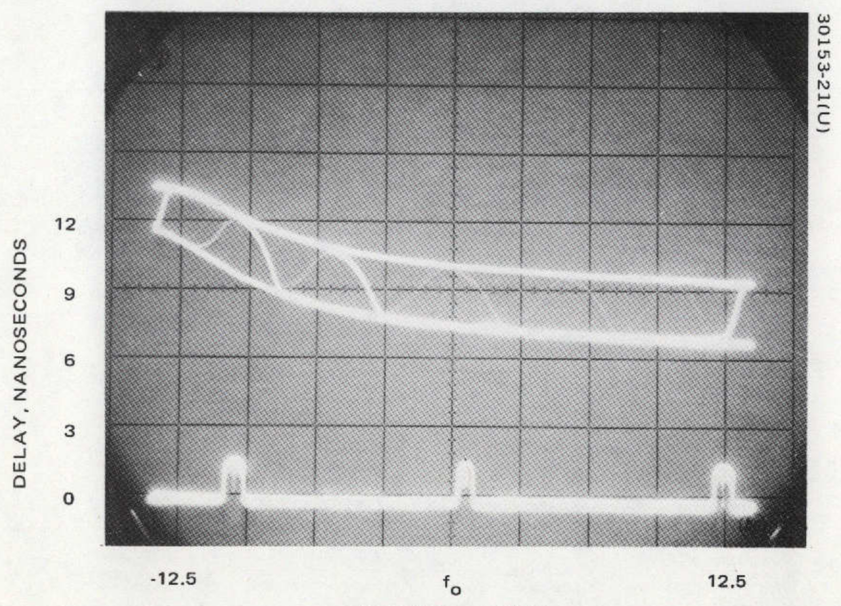


FIGURE 2-7. IF AMPLIFIER INTERMODULATION DISTORTION



a) VCO/IF AMPLIFIER COMBINATION



b) IF AMPLIFIER ALONE

FIGURE 2-8. LINK ANALYZER DISPLAY FOR GROUP DELAY TEST

TABLE 2-11. COMMUNICATION MODE BASEBAND FREQUENCY RESPONSE

VCO Input Frequency at 1 Volt Peak-to-Peak Amplitude	Corrected Demodulator Frequency Response, dB with respect to 10 kHz
0.1 Hz	<1 dB
10 Hz	0 dB
10 KHz	0 dB (ref)
100 KHz	0 dB
1 MHz	0 dB
5 MHz	-1 dB

Decoding of the command signals is accomplished by either of the two redundant spacecraft command decoders and each distinct command is furnished to the experiment on a separate wire from each decoder. All command signals furnished to the experiment are single pulse signals having the characteristics shown in Figure 2-9.

Command Interface

The command signals enter the experiment at a single 50 pin connector. Two pins on the connector are dedicated for each command, one for the signal from each spacecraft command decoder. The 22 commands are listed in Table 2-12 along with the pin numbers on experiment command interface connector (which is designated 301J1). From connector 301J1 the signals are distributed to the various interface circuits within the experiment.

The command interface circuits in the experiment are all essentially the same. A schematic of the typical circuit used is shown in Figure 2-10. The input has a diode OR gate so that the circuit will respond to a pulse from either spacecraft decoder. The OR gate is followed by a buffer amplifier to isolate the rest of the experiment circuitry from the command subsystem. In several cases, more than one of these command interface circuits are tied to a single command signal input. The input impedance level of the circuits has been chosen so that when as many as four circuits are tied to one line (the maximum case), the maximum current demand from the command subsystem is 6 ma during the ON condition of the pulse. All command circuits are in a state ready to receive command signals whenever power from either spacecraft load interface circuit is applied.

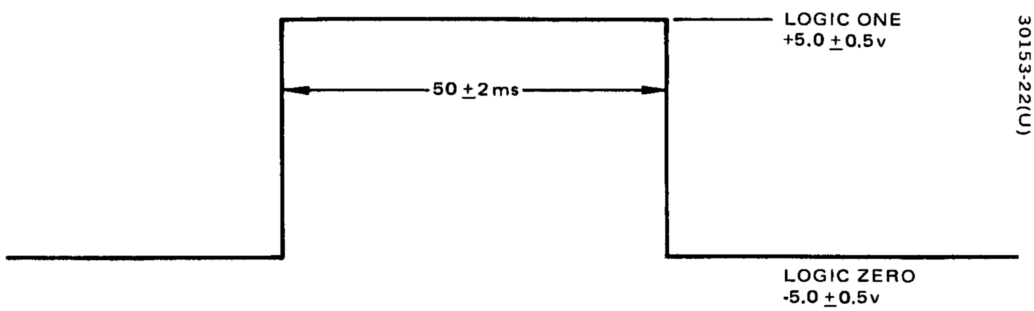


FIGURE 2-9. COMMAND SIGNAL PULSE CHARACTERISTICS

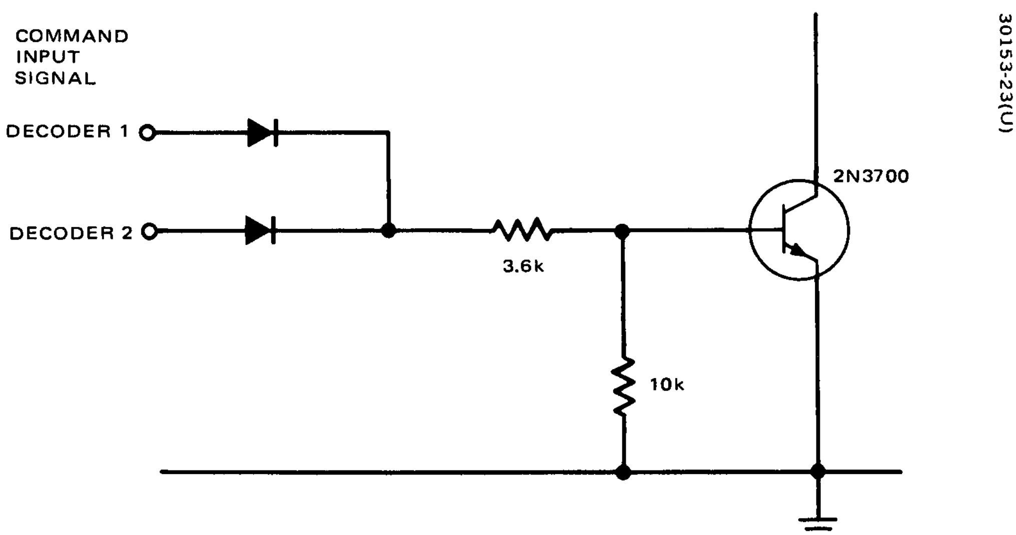


FIGURE 2-10. TYPICAL EXPERIMENT COMMAND INTERFACE CIRCUIT

TABLE 2-12. COMMAND SIGNAL PIN CONNECTIONS ON CONNECTOR 301J1

Item	Command Designation		Pin No.
1	Master Oscillator A	ON	1, 2
2	Master Oscillator B	ON	3, 4
3	Multiplier Chain A	ON	5, 6
4	Multiplier Chain B	ON	7, 8
5	Multiplier Chains	OFF	9, 10
6	Multitone mode	ON	41, 42
7	Communications mode	ON	45, 46
8	Continuous wave mode	ON	43, 44
9	20 GHz (HA) filament	ON	15, 16
10	20 GHz (HA) high voltage	ON	19, 20
11	20 GHz (HA)	OFF	17, 18
12	20 GHz (PA) filament	ON	21, 22
13	20 GHz (PA) high voltage	ON	25, 26
14	20 GHz (PA)	OFF	23, 24
15	30 GHz (HA) filament	ON	27, 28
16	30 GHz (HA) high voltage	ON	31, 32
17	30 GHz (HA)	OFF	29, 30
18	30 GHz (PA) filament	ON	33, 34
19	30 GHz (PA) high voltage	ON	37, 38
20	30 GHz (PA)	OFF	35, 36
21	Load Interface Circuit cross-connect	ON	49, 50
22	Load Interface Circuit cross-connect	OFF	47, 48
–	Command return		11, 12

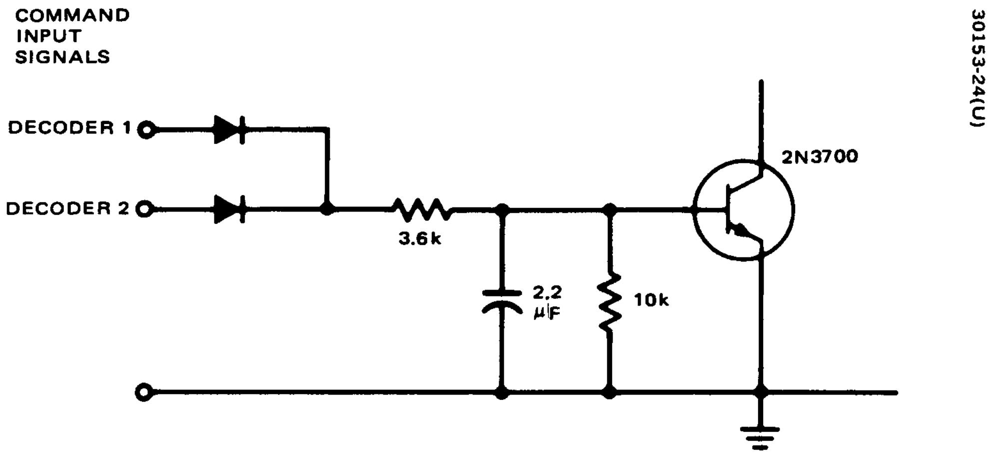


FIGURE 2-11. TRAVELING-WAVE TUBE AMPLIFIER HIGH VOLTAGE COMMAND INTERFACE CIRCUIT

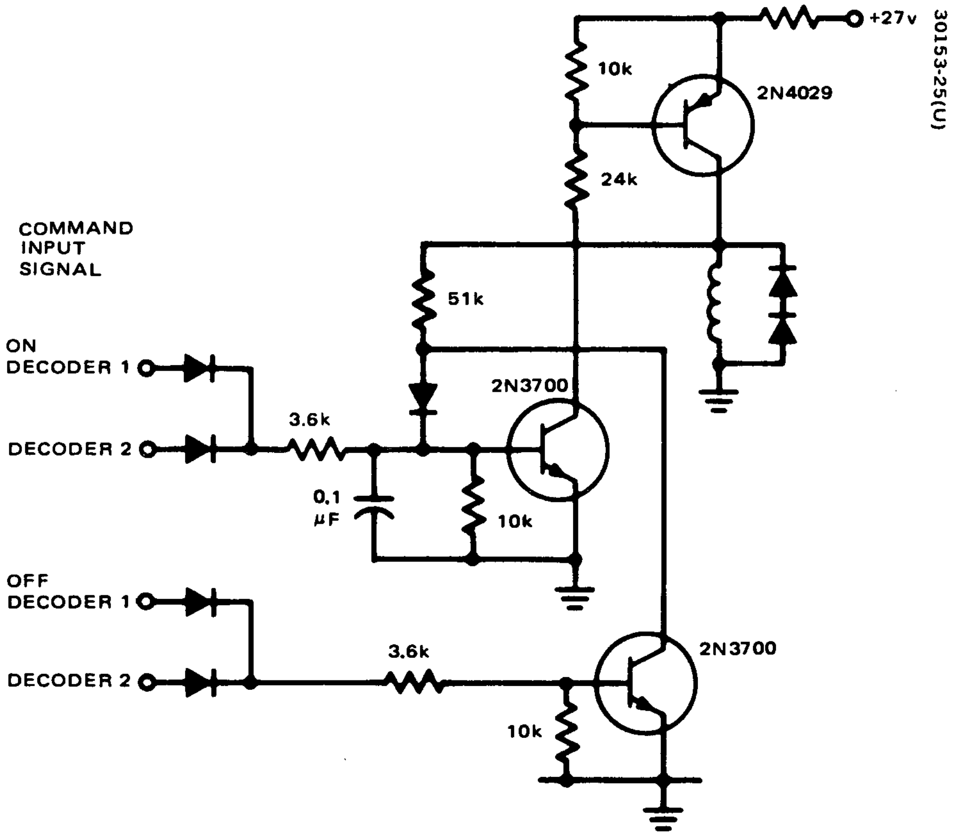


FIGURE 2-12. LOAD INTERFACE CIRCUIT CROSS-CONNECT COMMAND INTERFACE CIRCUIT

In the circuits which follow the interface circuit in all ON command paths there is capacitive decoupling. This has been provided so that if there is a command subsystem failure that presents a continuous ON level voltage to the experiment, the function may still be commanded OFF. In the OFF circuits, however, no such capacitor decoupling has been provided.

The two exceptions to the typical interface circuit are the TWTA high voltage ON command and the LIC cross-connect ON command. For the TWTA high voltage ON circuit, it was necessary to add a capacitor to ground to desensitize the circuit to noise spikes, and the resulting circuit is shown in Figure 2-11. In the LIC cross-connect ON circuit an electrical latch feedback signal was applied at the transistor input as shown in Figure 2-12.

Tests have been performed to verify that all commands can be executed in response to signals from either spacecraft decoder. Tests with varying amplitude pulses show that there is considerable margin in the experiment beyond the ±0.5 volt tolerance on the pulse height out of the spacecraft decoder. Tests have also been performed using very narrow pulses as might be expected from noise. The results varied, depending upon the particular command circuit and upon the amplitude of the narrow pulse, but the minimum pulse width to which any circuit would respond was 100 microseconds, which seems to be out of the noise regime.

Summary of Commands and Responses

A complete list of the commands required to operate the experiment is given in Table 2-13 along with the operational response which should occur for each. More detail on the specific response within the experiment is given in the paragraphs that follow. A typical sequence of turning on the experiment in the multitone mode is given in Table 2-14 including the two LIC turnon commands which are separate from the experiment itself.

Master Oscillator Commands

There are two commands associated with the master oscillators: Master Oscillator A ON and master Oscillator B ON. Assuming that neither oscillator is on and that power is being supplied from a LIC, a master Oscillator A ON command will turn on the master oscillator Regulator A which then supplies dc power to the Oscillator A oven and circuitry. Subsequent receipt of a master Oscillator B ON command does two things: turns off master Oscillator A regulator and turns on master Oscillator B regulator, which in turn supplies dc power to the Oscillator B oven and circuitry. The only way to turn off both oscillators is to remove the LIC voltages, in which case even though the LIC is turned back on, the oscillator will not come on until commanded to do so.

Multiplier Chain Commands

There are three commands associated with the multiplier chains: multiplier Chain A ON, multiplier chain B ON, and multiplier chains OFF.

TABLE 2-13. MILLIMETER WAVE EXPERIMENT COMMAND VERSUS RESPONSE LIST

Command/Response		Regulator for Master Oscillator A	Regulator For Master Oscillator B	Regulator For Multiplier Chain A	Regulator For Multiplier Chain B	Multiplier Selection Circulator Switches for 20 and 30 GHz	Regulator For Multitone Processor	Regulator For Communication Processor	Mode Selection Circulator Switches for 20 and 30 GHz	20 GHz TWT Power Supply HA Filament Converter	20 GHz TWT Power Supply HA High Voltage Converter	20 GHz TWT Power Supply PA Filament Converter	20 GHz TWT Power Supply PA High Voltage Converter	30 GHz TWT Power Supply HA Filament Converter	30 GHz TWT Power Supply HA High Voltage Converter	30 GHz TWT Power Supply PA Filament Converter	30 GHz TWT Power Supply PA High Voltage Converter	LIC Cross-Connect Relay
Master Oscillator A	ON	ON	OFF	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Master Oscillator B	ON	OFF	ON	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Multiplier chain A	ON	–	–	ON	OFF	A	–	–	–	–	–	–	–	–	–	–	–	–
Multiplier chain B	ON	–	–	OFF	ON	B	–	–	–	–	–	–	–	–	–	–	–	–
Multiplier chains	OFF	–	–	OFF	OFF	–	–	–	–	–	–	–	–	–	–	–	–	–
Multitone mode	ON	–	–	–	–	–	ON	OFF	MT	–	–	–	–	–	–	–	–	–
Communication mode	ON	–	–	–	–	–	OFF	ON	COMM	–	–	–	–	–	–	–	–	–
Continuous wave mode	ON	–	–	–	–	–	OFF	OFF	MT	–	–	–	–	–	–	–	–	–
20 GHz HA filament	ON	–	–	–	–	–	–	–	–	ON	–	–	–	–	–	–	–	–
20 GHz HA high voltage	ON	–	–	–	–	–	–	–	–	–	ON	–	–	–	–	–	–	–
20 GHz HA	OFF	–	–	–	–	–	–	–	–	OFF	OFF	–	–	–	–	–	–	–
20 GHz PA filament	ON	–	–	–	–	–	–	–	–	–	–	ON	–	–	–	–	–	–
20 GHz PA high voltage	ON	–	–	–	–	–	–	–	–	–	–	–	ON	–	–	–	–	–
20 GHz PA	OFF	–	–	–	–	–	–	–	–	–	–	OFF	OFF	–	–	–	–	–
30 GHz HA filament	ON	–	–	–	–	–	–	–	–	–	–	–	–	ON	–	–	–	–
30 GHz HA high voltage	ON	–	–	–	–	–	–	–	–	–	–	–	–	–	ON	–	–	–
30 GHz HA	OFF	–	–	–	–	–	–	–	–	–	–	–	–	OFF	OFF	–	–	–
30 GHz PA filament	ON	–	–	–	–	–	–	–	–	–	–	–	–	–	–	ON	–	–
30 GHz PA high voltage	ON	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	ON	–
30 GHz PA	OFF	–	–	–	–	–	–	–	–	–	–	–	–	–	–	OFF	OFF	–
Load Interface Circuit cross-connect	ON	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	Close
Load Interface Circuit cross-connect	OFF	–	–	–	–	–	–	–	–	OFF*	OFF*	OFF*	OFF*	OFF*	OFF*	OFF*	OFF*	Open

*Depending upon which load interface circuit is on.

TABLE 2-14. TYPICAL TURNON SEQUENCE FOR MULTITONE MODE

Sequence No.	Command	
1	Millimeter wave experiment Load Interface Circuit 1	ON
2	Millimeter wave experiment Load Interface Circuit 2	ON
3	Master Oscillator A (allow 20 minutes stabilization time)	ON
4	Multiplier Chain A	ON
5	Continuous wave mode	ON
6	20 GHz parabolic antenna filament (allow 90 seconds warmup time)	ON
7	20 GHz parabolic antenna high voltage	ON
8	30 GHz parabolic antenna filament (allow 90 seconds warmup time)	ON
9	30 GHz parabolic antenna high voltage	ON
10	Multitone mode	ON

Assuming that both multipliers are off, a multiplier chain A ON command will cause four actions: 1) multiplier chain regulator A will go on which in turn supplies dc power to all of the A chain multiplier modules in the RF multiplier unit, 2) switch driver module will pulse the communications 10 GHz circulator switch to the state in which the communications channels may receive 10 GHz power from the A chain, 3) switch driver module pulses the 20 GHz circulator switch to the state in which the TWTAs may receive 20 GHz signals from the A phase modulator/X2 multiplier set, and 4) switch driver module pulses the 30 GHz circulator switch to the state in which the TWTAs may receive 30 GHz signals from the A phase modulator/X3 multiplier set. Pulses are supplied to the circulator switches even though they may already be in the proper state.

Subsequent receipt of a multiplier chain B ON command will cause five actions: 1) multiplier chain regulator A will go off, thus removing dc power from the A chain multiplier modules; 2) multiplier chain regulator B will go on which in turn supplies dc power to the B chain multiplier modules in the RF multiplier unit; 3) the switch driver module pulses the communications 10 GHz circulator switch to the state in which the communications channels may receive 10 GHz power from the B chain; 4) the switch driver module pulses the 20 GHz circulator switch to the state in which the TWTAs may receive 20 GHz signals from the B phase modulator/X2 multiplier set; and 5) the switch driver module pulses the 30 GHz circulator switch to the state in which the TWTAs may receive 30 GHz signals from the B phase modulator/X3 multiplier set.

Receipt of the multiplier chains OFF command turns off whichever multiplier chain regulator is on, thus removing dc power from all multiplier modules in the RF multiplier unit. Removal of LIC power will also accomplish this same action in which case the multiplier chains will not again turn on unless commanded to do so. In either turnoff situation the circulator switches will remain in the last commanded state.

Mode Commands

Selection of experiment operating mode is accomplished by issuing one of three commands: CW mode ON, multitone mode ON, or communications mode ON. To initialize the system it is advisable to issue the CW mode ON command first, even though there will be no modulation applied to the carrier until one of the other two modes is commanded. The reason is that the last operating mode before turnoff may have been communications mode, in which case the 10 GHz will be applied to the communications channels and without modulation there will be no output.

Assuming the experiment had been off, receipt of the CW mode ON command causes the switch driver module to pulse both the A and B mode switching 10 GHz circulator switches to the state in which the phase modulators may receive 10 GHz power. Pulses to the circulator switches are supplied even though they may already be in the proper state. Both the multitone regulators and communication regulators will receive the command as an off signal, but since neither is on, no action will take place.

Subsequent receipt of the multitone mode ON command will cause both of the multitone regulators to go on, which in turn will supply dc power to all the multitone amplifier modules and bias to all the phase modulators. The command will also cause the switch driver module to pulse both the A and B mode switching circulator switches to ensure they will be in the state to supply 10 GHz power to the phase modulators. This provision was made in case it was desired to go directly to multitone mode without CW mode initialization or to switch from communications mode to multitone mode directly.

Subsequent receipt of the communications mode ON command causes two actions: 1) the communications regulator is turned on which then supplies dc power to the VCO and IF amplifier modules, and 2) the switch driver module pulses both the A and B modes switching 10 GHz circulator switches to the state in which 10 GHz power may be supplied to the communications channels.

As was previously indicated the CW mode ON command causes the multitone regulators and the communication regulator to go OFF, thus removing dc power from the multitone amplifiers, VCO, and IF amplifier. It also causes the switch driver module to pulse the 10 GHz circulator switches back to the state which allows 10 GHz power to flow to the phase modulators. It is advisable to use the CW mode ON command as an intermediate step when switching from multitone mode to communications mode or vice versa. The reason is that it is the only way of turning OFF the multitone regulators and the communication regulator other than by removing LIC power from the experiment. To leave either one on would waste one or two watts of spacecraft power.

TWTA Commands

Each of the four TWTAs has associated with it three commands and the operation in each case is the same. The three commands for the 20 GHz TWTA operating into the parabolic antenna are the 20 GHz parabolic antenna filament ON, 20 GHz parabolic antenna high voltage ON, and 20 GHz parabolic antenna OFF.

Assuming the LICs are ON, the first command to be issued is the 20 GHz parabolic antenna filament ON command which turns on the preregulator and filament inverter in the 20 GHz parabolic antenna power supply, which in turn starts the heating up of the TWT filament. After waiting for at least 90 seconds, the 20 GHz parabolic antenna high voltage ON command may be issued and this causes the high voltage converters in the 20 GHz parabolic antenna power supply to turn ON and the TWTA is then operational. If the 20 GHz parabolic antenna high voltage ON command is issued prior to the 20 GHz parabolic antenna filament ON command no action will take place since the power supply preregulator will be OFF. However, if the 20 GHz parabolic antenna high voltage ON command is issued less than 90 seconds after the 20 GHz parabolic antenna filament ON command, high voltages will go ON and damage to the TWT could occur. Receipt of the 20 GHz parabolic antenna OFF command causes the 20 GHz parabolic antenna power supply preregulator to go OFF, thus removing both filament and high voltage from the TWT. Removal of LIC 1 power will also accomplish this OFF action.

LIC Cross-Connect Commands

Since in the normal configuration a particular TWTA can only be powered from one of the LICs, it would not be possible to utilize this TWTA in the event of failure of the LIC. To avoid this problem provision has been made to connect the two LIC buses together by command. In this way any TWTA may be powered by whichever LIC is still operable.

Two commands are associated with the LIC cross-connect function: LIC cross-connect ON and LIC cross-connect OFF. Receipt of the LIC cross-connect ON command causes an electrically latching relay to close which connects the two LIC bus lines together through isolation diodes. Receipt of the LIC cross-connect OFF command disables the electrical latch and the relay opens.

TABLE 2-15. MILLIMETER WAVE EXPERIMENT TELEMETRY CHANNEL LIST

Item	Channel	Units	Range	Discrete	Analog	Accuracy percent	Rate
1	Master Oscillator A ON	N/A	ON-OFF	D		N/A	1/3
2	Master Oscillator B ON	N/A	ON-OFF	D		N/A	1/3
3	Multiplier Chain A ON	N/A	ON-OFF	D		N/A	1/3
4	Multiplier Chain B ON	N/A	ON-OFF	D		N/A	1/3
5	Multitone mode ON	N/A	ON-OFF	D		N/A	1/3
6	Communications mode ON	N/A	ON-OFF	D		N/A	1/3
7	20 GHz TWT horn antenna filament ON	N/A	ON-OFF	D		N/A	1/3
8	20 GHz TWT horn antenna high voltage ON	N/A	ON-OFF	D		N/A	1/3
9	20 GHz TWT parabolic antenna filament ON	N/A	ON-OFF	D		N/A	1/3
10	20 GHz TWT parabolic antenna high voltage ON	N/A	ON-OFF	D		N/A	1/3
11	30 GHz TWT horn antenna filament ON	N/A	ON-OFF	D		N/A	1/3
12	30 GHz TWT horn antenna high voltage ON	N/A	ON-OFF	D		N/A	1/3
13	30 GHz TWT parabolic antenna filament ON	N/A	ON-OFF	D		N/A	1/3
14	30 GHz TWT parabolic antenna high voltage ON	N/A	ON-OFF	D		N/A	1/3
15	20 GHz horn antenna power monitor	mw	0 to 3000		A	1	1/3
16	20 GHz parabolic antenna power monitor	mw	0 to 3000		A	1	1/3
17	30 GHz horn antenna power monitor	mw	0 to 3000		A	1	1/3
18	30 GHz parabolic antenna power monitor	mw	0 to 3000		A	1	1/3
19	Experiment load interface circuit Voltage 1	volts	0 to 35/70		A	3	1/48
20	Experiment load interface circuit Voltage 2	volts	0 to 35		A	3	1/48
21	2 GHz power out Multiplier A	mw	0 to 3000		A	3	1/48
22	2 GHz power out Multiplier B	mw	0 to 3000		A	3	1/48
23	Power amplifier temperature monitor	^{o}C	-10 to +45		A	3	1/48
24	Modulator temperature monitor	^{o}C	-10 to +45		A	3	1/48

TELEMETRY

The complement of telemetry monitoring points within the experiment has been designed to provide three kinds of information. The first type of information is configuration status, and this is provided by 14 discrete or bilevel signals from significant points within the experiment. The second type of data is that used for in-orbit calibration of the performance of the system, and this is provided by four RF power output monitoring analog signals and two temperature monitoring analog signals. The third category of information is used for in-orbit degradation and failure analysis with the main purpose here being determination of the best configuration to put the subsystem into "to continue" operations. Data for this latter type of information is acquired on four additional analog channels.

A summary list of the 24 telemetry channels is given in Table 2-15, including the approximate range of measurement and required telemetry accuracy for analog channels and the required sampling rate for all channels. A more detailed description of the channels with performance data is given in the following paragraphs. The telemetry signals are supplied out of the experiment on two identical connectors (identified as 301J2 and 301J3), one to each of the spacecraft telemetry encoders. The pin numbers on these connectors for each channel are listed in Table 2-16.

Bilevel Channels

The 14 bilevel channels indicate the ON or OFF status of circuits, modules, or groups of modules within the experiment. A 0 volt output signal indicates the item is OFF and a signal in the range of 5 to 8 volts dc indicates the item is ON. In each case the channel is monitoring the regulated dc voltage being supplied to the item in question, and this voltage lies in the range of 23.5 to 25.7 volts dc, depending on the particular application.

With the exception of the four TWTA high voltage ON channels, all of the bilevel telemetry interface circuits are identical as shown in Figure 2-13. The only difference for the high voltage ON channels is the addition

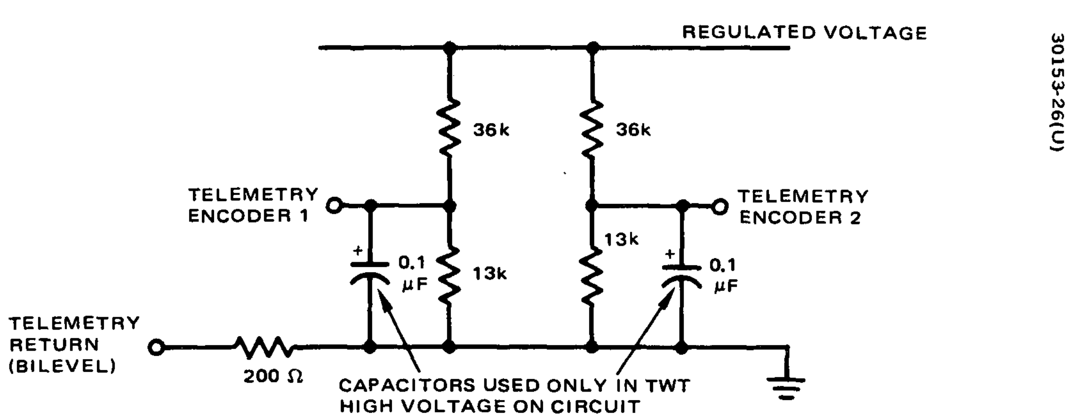


FIGURE 2-13. BILEVEL TELEMETRY MONITOR CIRCUIT

TABLE 2-16. PIN CONNECTIONS ON CONNECTORS 301J2 AND 301J3
FOR TELEMETRY CHANNELS

Item	Description	Pin Number
1	Master Oscillator A ON	1
2	Master Oscillator B ON	2
3	Multiplier Chain A ON	3
4	Multiplier Chain B ON	4
5	Multitone mode ON	17
6	Communications mode ON	18
7	20 GHz TWT horn antenna filament ON	7
8	20 GHz TWT horn antenna high voltage ON	8
9	20 GHz TWT parabolic antenna filament ON	9
10	20 GHz TWT parabolic antenna high voltage ON	10
11	30 GHz TWT horn antenna filament ON	11
12	30 GHz TWT horn antenna high voltage ON	12
13	30 GHz TWT parabolic antenna filament ON	13
14	30 GHz TWT parabolic antenna high voltage ON	14
15	20 GHz horn antenna power monitor	19
16	20 GHz parabolic antenna power monitor	20
17	30 GHz horn antenna power monitor	21
18	30 GHz parabolic antenna power monitor	22
19	Experiment load interface circuit Voltage 1	36
20	Experiment load interface circuit Voltage 2	37
21	2 GHz power out Multiplier A	33
22	2 GHz power out Multiplier B	32
23	Power amplifier temperature monitor	24
24	Modulator temperature monitor	25
-	Telemetry return (analog)	30
-	Telemetry return (bilevel)	29
-	Telemetry return (isolated)	31

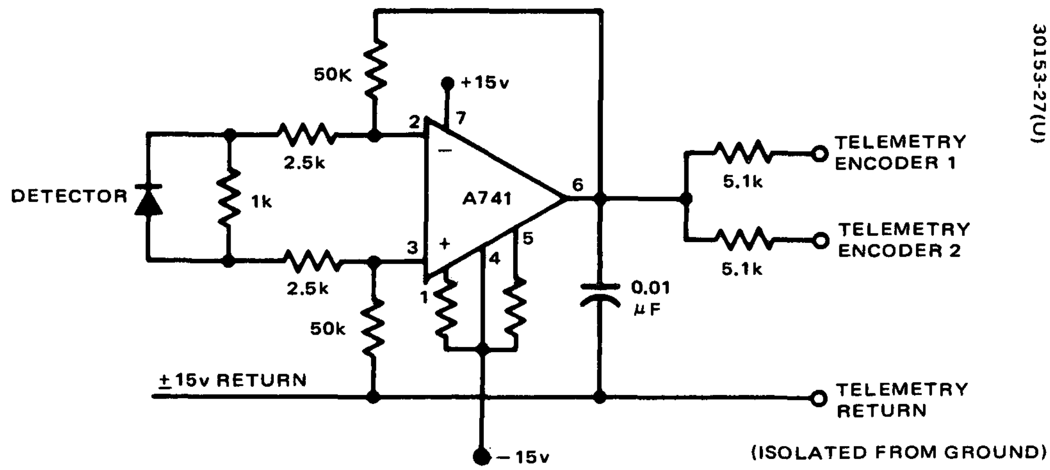


FIGURE 2-14. RF POWER MONITOR TELEMETRY CIRCUIT

of noise suppression capacitors in each output. As can be determined from the circuit diagram of Figure 2-13, each bilevel channel presents a source impedance of approximately 9.6 kilohms to the telemetry encoder. In addition the individual output signals are isolated from one another by the value of the divider resistors.

Qualification level temperature tests of the experiment show that the maximum variation in output level for the bilevel channels is well within the -2.0 to +0.3 volts dc requirement for logic zero and well within the +3.0 to +8.0 volts dc requirement for logic one.

RF Output Power Monitor Channels

The four power monitors measure the output power very close to the output ports of the four TWTAs; two at 20 GHz and two at 30 GHz. In each case the RF power is sampled by a cross-guide coupler and applied to a crystal detector. The dc signal out of the crystal detector is amplified by an operational amplifier to the 0 to 5 volt analog telemetry range.

The telemetry interface circuit for the power monitors is shown in Figure 2-14. The source impedance presented to the telemetry encoder is the 5.1 kilohm series isolation resistance placed in each output line. The output signal is referenced to the telemetry return line which is common to these four power monitor channels and isolated from power and chassis grounds in the experiment.

Performance of the power monitors was tested at the module level since it is not possible to vary the input to the monitors in the complete experiment configuration. The transfer characteristics of the monitors, i.e., telemetry output voltage versus RF power, at room temperature is shown on Figure 2-15. Single point calibration of the power monitors as a function of temperature were made during experiment testing, and the results are given in Table 2-17.

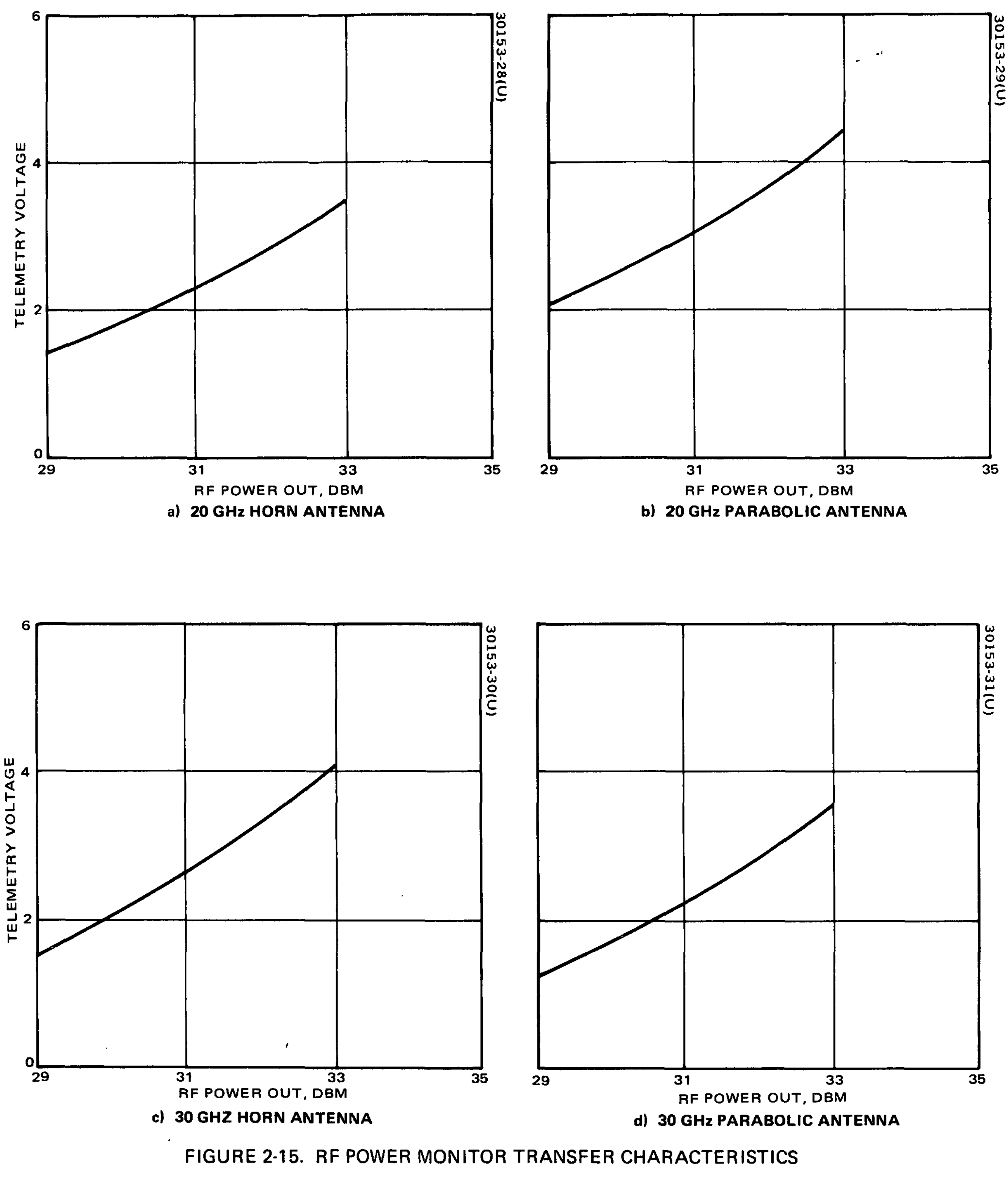


FIGURE 2-15. RF POWER MONITOR TRANSFER CHARACTERISTICS

TABLE 2-17. CW RF OUTPUT POWER AND CORRESPONDING POWER MONITOR TELEMETRY OUTPUT VOLTAGES AT VARIOUS TEMPERATURES

Power* Monitor	5°C		23°C		35°C	
	RF Output Power, dBm	Telemetry Reading, vdc	RF Output Power, dBm	Telemetry Reading, vdc	RF Output Power, dBm	Telemetry Reading, vdc
20 HA	33.82	4.25	33.84	4.10	33.66	3.45
20 PA	32.18	3.70	32.85	4.08	33.05	4.29
30 HA	32.66	3.31	32.64	3.39	32.46	3.33
30 PA	33.37	3.89	33.65	4.08	33.39	3.96

*20 HA indicates power monitor at output of 20 GHz TWTA associated with horn antenna; 20 PA the 20 GHz TWTA for parabolic antenna; 30 HA the 30 GHz TWTA for horn antenna; and 30 PA the 30 GHz TWTA for parabolic antenna. All measurements were made using the A multiplier chain.

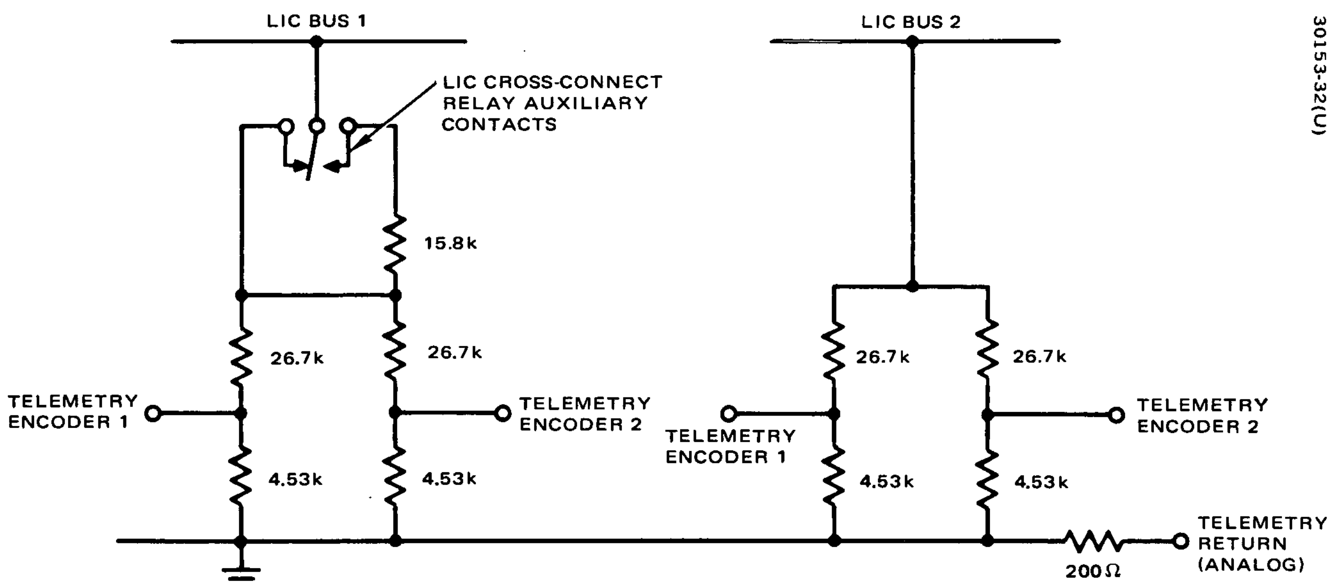


FIGURE 2-16. LOAD INTERFACE CIRCUIT BUS VOLTAGE TELEMETRY CIRCUITS

Experiment LIC Voltage Channels

The two channels monitoring the LIC voltages are simply precision resistive voltage dividers as shown in Figure 2-16. Under normal operating conditions the scale factor of both voltage dividers is 0.145. However, when the LIC cross-connect relay is ON, the scale factor for the LIC bus voltage No. 1 channel reduces to 0.072. This scale factor change provides an indication of the status of the LIC cross-connect relay. The source impedance that the circuits present to the spacecraft telemetry encoders is approximately 3.9 kilohms, and the various signal lines are isolated from one another by the divider resistors.

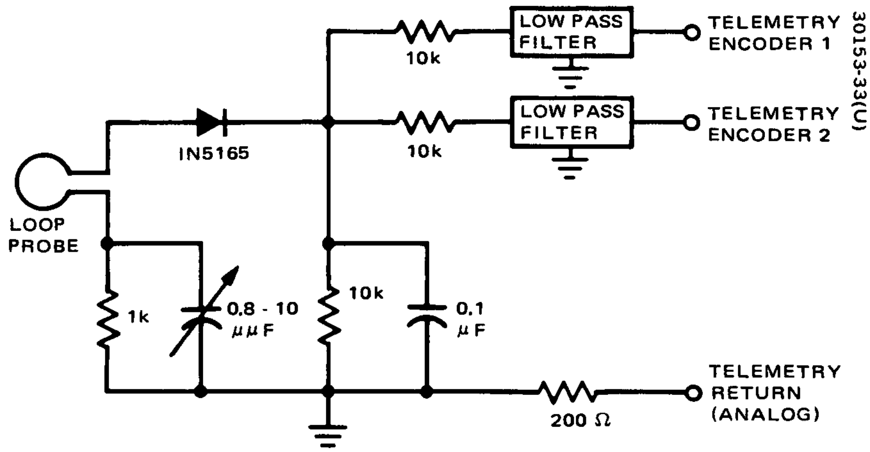


FIGURE 2-17. 2 GHz POWER MONITOR CIRCUIT

2 GHz Power Monitor Channels

The 2 GHz power monitor channels measure the power output of the two 2 GHz power amplifier modules in the RF multiplier unit. Essentially a loop probe in the output tuned circuit samples a small amount of the RF energy and this is detected by a crystal diode which provides sufficient dc voltage for the telemetry signal without further amplification. The interface circuit is shown in Figure 2-17. The source impedance presented to the telemetry encoder is essentially the 10 kilohm isolation resistor provided in the lines to each encoder.

The transfer characteristic of the monitors, i.e., telemetry voltage versus 2 GHz power, was not measured during the qualification tests since it is not possible to vary the power level in the complete system. The 2 GHs power monitor telemetry voltage was recorded as a function of temperature and is presented in Figure 2-18 to provide an indication of normal operation.

Temperature Monitor Channels

Two temperature monitors are included in the experiment, one on the main deck of the 20/30 GHz modulator/power amplifier unit near the collector end of the 30 GHz TWTs and the second on the modulation deck of this same unit near the phase modulation modules. Each monitor circuit consists of a voltage divider with one element of the divider being a thermistor as shown in Figure 2-19. The source impedance presented to the telemetry encoder varies with temperature but at 25°C it is approximately 5 kilohms, including the 3.3 kilohm isolation resistors in the lines to the encoders. The telemetry output voltage for various temperatures measured with calibrated thermocouples mounted in the same location is shown in Table 2-18.

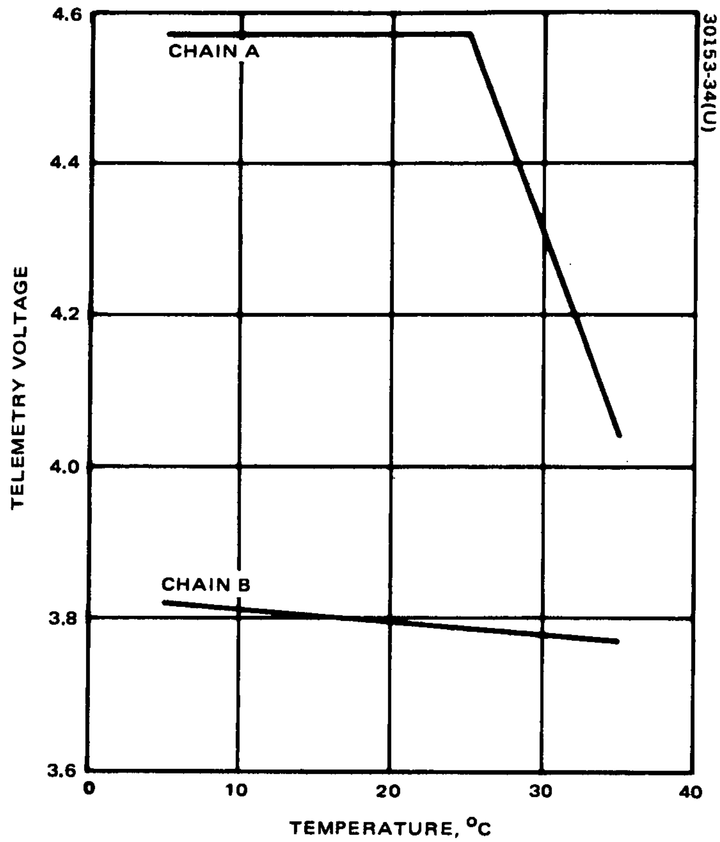


FIGURE 2-18. 2 GHz POWER MONITOR TELEMETRY

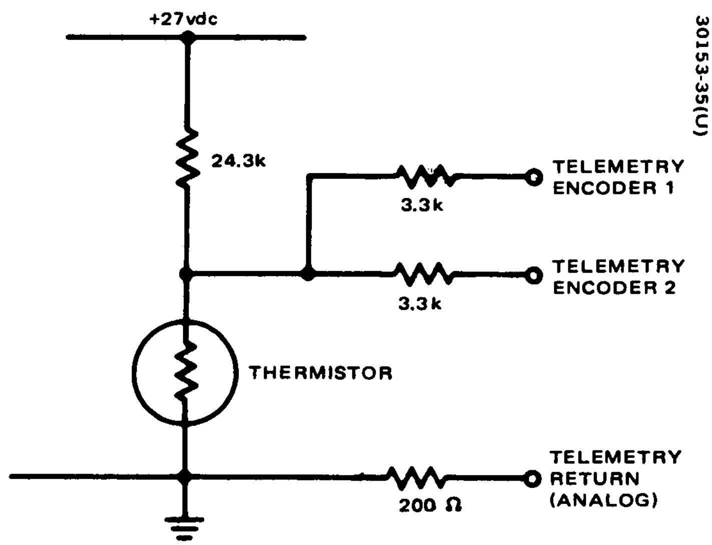


FIGURE 2-19. TEMPERATURE MONITOR CIRCUIT

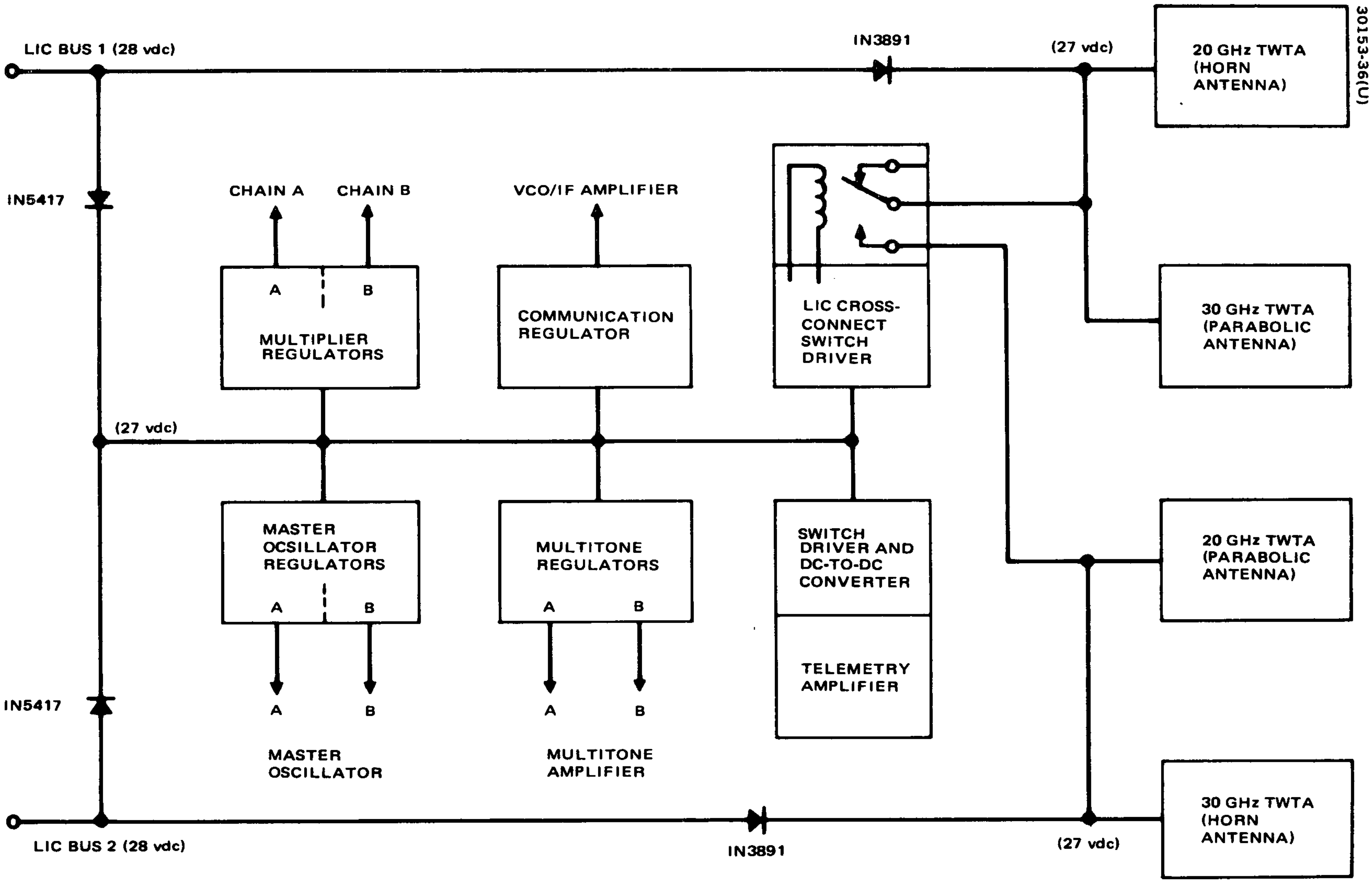


FIGURE 2-20. ELECTRICAL POWER SYSTEM BLOCK DIAGRAM

TABLE 2-18. TEMPERATURE MONITOR TELEMETRY OUTPUT VOLTAGES AT VARIOUS TEMPERATURES

Temperature, °C	Temperature Monitor Telemetry Output Voltage, Vdc	
	TWTA Deck	Modulator Deck
- 5	2.15	2.04
+ 5	2.32	2.2
+23	2.67	2.54
+35	2.91	2.77
+50	3.21	3.07

TABLE 2-19. POWER INTERFACE CONNECTOR PIN DESIGNATIONS

Item	Description	Pin No.
1	Experiment LIC 1	1, 2
2	Experiment LIC 2	7, 8
3	Experiment return	9, 10, 14, 15
4	Chassis ground	5, 12

POWER SYSTEM

The electrical power system of the experiment is shown in block diagram form in Figure 2-20. Bus voltages of 28 volts dc from the two millimeter wave experiment load interface circuits enter the experiment and are connected together through 1N5417 isolation diodes. This common bus voltage, which is approximately 27 volts dc, is used to power all of the experiment circuits except the TWTAs. Normally each LIC supplies only one of the pair of operating TWTAs, i. e., when using the parabolic antenna, LIC 1 supplies the 30 GHz TWTA and LIC 2 supplies the 20 GHz (TWTA. Conversely, when using the horn antennas, LIC 1 supplies the 20 GHz TWTA and LIC 2 supplies the 30 GHz TWTA. In the abnormal, LIC cross-connect configuration, the LIC buses are tied together through the 1N3891 isolation diodes and the cross-connect relay contact. In this configuration any TWTA can be operated from either LIC.

All dc power is connected to the experiment through a single 15 pin connector, designated as 301J4. The connections to each pin of this connector are listed in Table 2-19.

Whenever LIC voltages are applied, all command interface circuits are activated, LIC telemetry monitor circuits are energized, temperature monitor telemetry circuits are energized, and dc to dc converter and amplifiers associated with the RF power monitors are operating. The command interface circuits draw an insignificant amount of power except during a command pulse, and the telemetry circuits require approximately 25 ma of current for a total power requirement in the experiment off state of 0. 7 watt.

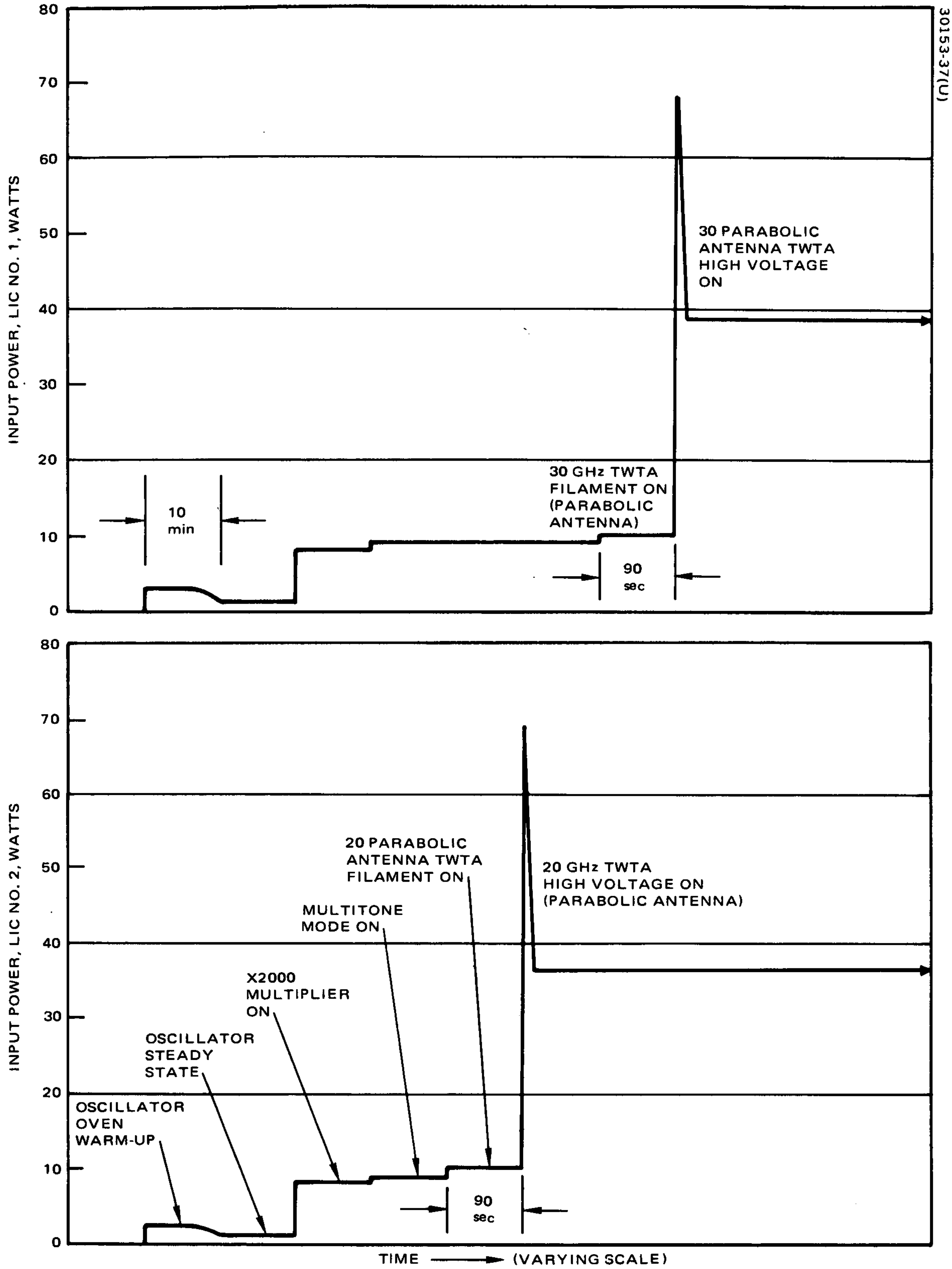


FIGURE 2-21. EXPERIMENT POWER PROFILE

Operating Voltage Limits

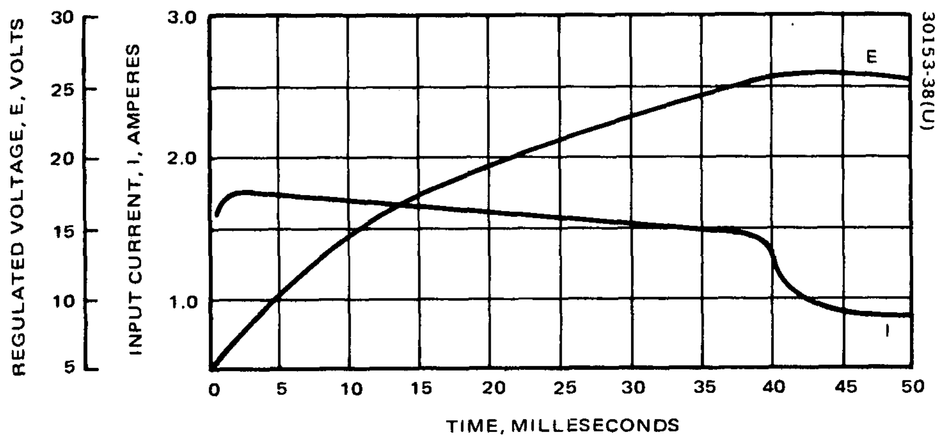
Although the specified voltage limits over which the experiment must operate properly are only ±2 percent (±0.56 volt about the 28 volts dc nominal, satisfactory operation is achieved above the upper limit and operation with some degradation is possible below the lower limit. All circuits will perform within specifications with a bus voltage as high as 32 volts dc. In addition the TWTAs will operate properly with a bus voltage as low as 26 volts dc. Automatic turn off of the TWTA power supplies occurs at 23 volts dc to prevent damage to the TWTs. Satisfactory operation of the rest of the experiment is possible down to 27 volts dc with slightly degraded performance occurring as the voltage is decreased to 26 volts dc. No damage will occur in any of the experiment if the voltage goes below these values, nor will damage occur if the voltage goes as high as 36 volts dc.

Input Power

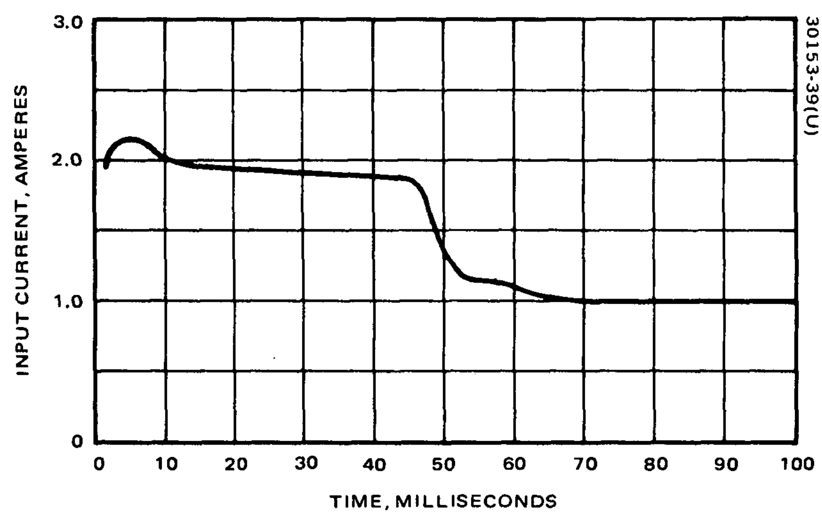
The first step in turning on the experiment is to turn on the master oscillator. This results in an increase in input power from the LIC of about 4.5 watts for a total of 5.2 watts. This gradually decreases as the crystal oven reaches its stabilized temperature after about 10 minutes. At this point the total dc input power should be between 2.1 and 3.2 watts, depending on the ambient temperature. Successive turnon of the various portions of the experiment to a multitone mode configuration results in a total power profile as shown in Figure 2-21. In this profile it is assumed that each LIC will supply half of the load with the exception of the TWTA loads. The profile is somewhat approximate, and exact values of total power in the various modes over temperature (as measured in the thermal-vacuum chamber) are given in Table 2-20.

TABLE 2-20. DC INPUT POWER FOR VARIOUS MODES AND TEMPERATURES

Multiplier Chain	Mode	TWTAs	Power, watts		
			At +5°C	At +25°C	At +35°C
A	CW	None	18.33	16.83	15.84
B	CW	None	16.22	15.41	15.14
A	MT	None	18.47	18.81	17.80
B	MT	None	18.33	17.10	16.82
A	COMM	None	21.15	19.52	18.50
B	COMM	None	18.61	17.82	17.24
A	CW	20 HA	38.74	38.53	35.79
B	CW	20 HA	36.88	36.83	34.95
A	CW	20/30 HA	70.70	67.50	66.78
B	CW	20/30 HA	67.74	66.70	66.13
A	CW	20 PA	37.58	35.80	34.33
A	CW	20/30 PA	66.14	64.64	64.59



a) 20 GHz



b) 30 GHz

FIGURE 2-22. CURRENT TRANSIENTS AT TRAVELING–WAVE TUBE AMPLIFIER HIGH VOLTAGE TURNON

Transients and Noise

The primary transient current (other than the minor one of crystal oven stabilization previously discussed), occurs when the TWTA high voltage is turned ON. Typical current waveforms for these transients are shown in the oscilloscope photographs of Figures 2-22(a) and 2-22(b) for the 20 GHz TWTA and the 30 GHz TWTA, respectively. Noise on the power line is due to the TWTA power supply chopping waveform. Filtering has been incorporated so that the maximum current ripple on each LIC bus is 30 ma peak-to-peak. More detail on conducted interference and susceptibility is given in Section 4 of this report.

PHYSICAL CHARACTERISTICS

The millimeter wave experiment is designed to be mounted in the southeast quadrant of the earth viewing module (EVM) of the ATS-F spacecraft. The location of the various parts of the experiment is shown in Figure 2-23. The parabolic and horn antennas mount from the inside of the earth viewing surface of the EVM with the lips of the horn and the tunnel of the parabolic antenna extending through the thermal insulation to be flush with the outside surface. The Kapton thermal covers in their picture frame type holders are mounted on the outside of the earth viewing surface of the EVM over the antenna apertures. The RF multiplier unit mounts on the interior north-south web of the EVM, and the 20/30 GHz modulator/power amplifier unit mounts on the south wall of the EVM. Not shown in Figure 2-23 are the various coax and waveguide interconnections among the four major units. The electrical interface with the spacecraft is made at a group of connectors on the 20/30 GHz modulator/power amplifier unit. A photograph of the experiment on a frame somewhat simulating the spacecraft installation is shown in Figure 2-24.

Outline and Mounting

Detailed dimensions and mounting provisions for the units comprising the experiment are given in the GSFC Interface Control Drawings which are listed in Table 2-21 for reference.

The RF multiplier unit is a rectangular box approximately 14-1/2 inches long by 8-1/2 inches wide by 7 inches high with all connectors on one end. It is mounted to the interior north-south web of the EVM by ten No. 10-32 screws.

The 20/30 GHz modulator/power amplifier unit is an assembly of modules on a plate approximately 22-1/2 inches long by 21 inches wide. The height of the unit varies but the maximum height is 9 inches. The plate, with all of its subassemblies attached, is mounted to the south wall of the EVM with 39 No. 10-32 screws.

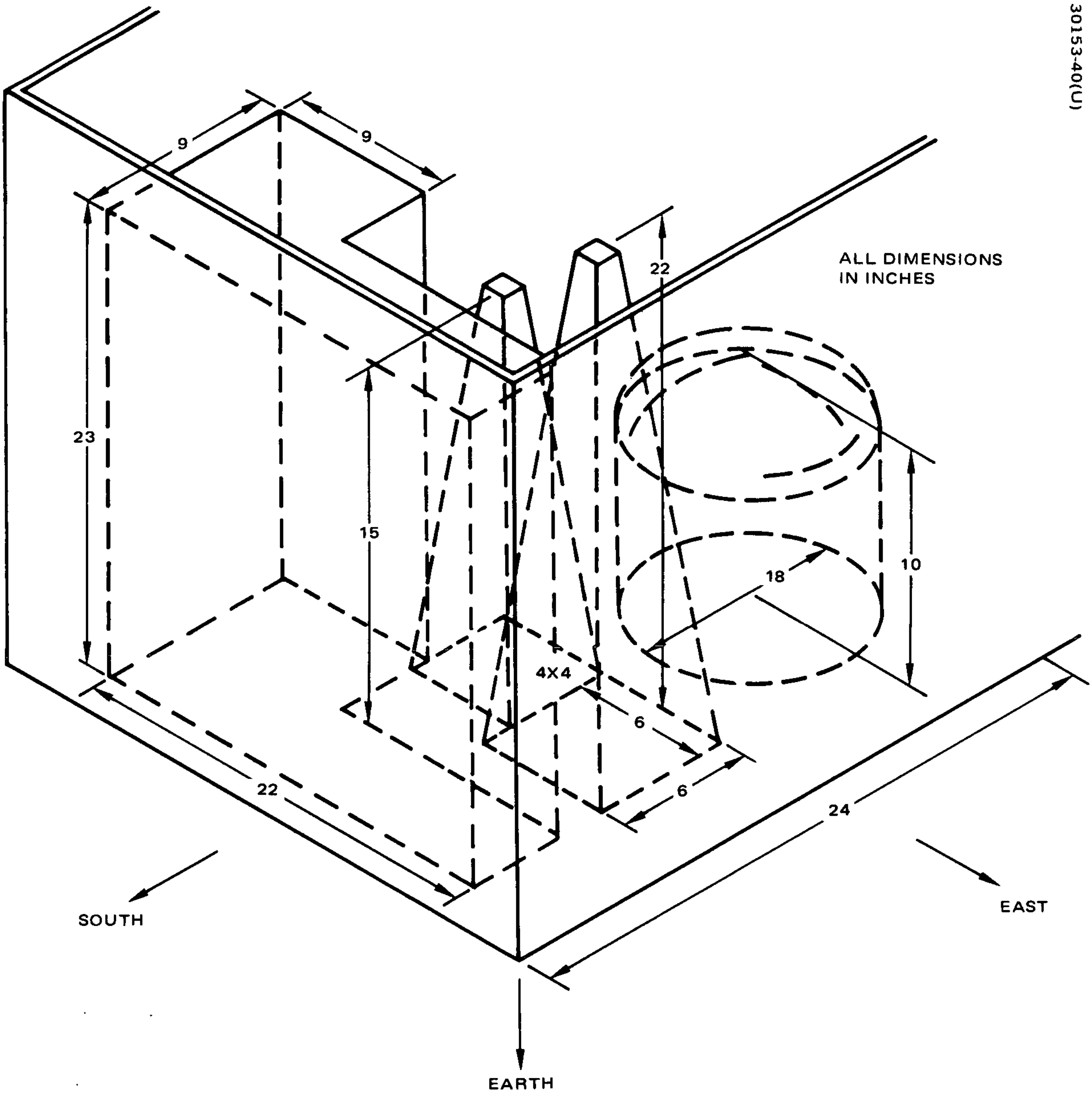


FIGURE 2-23. EXPERIMENT GENERAL ARRANGEMENT IN EARTH VIEWING MODULE

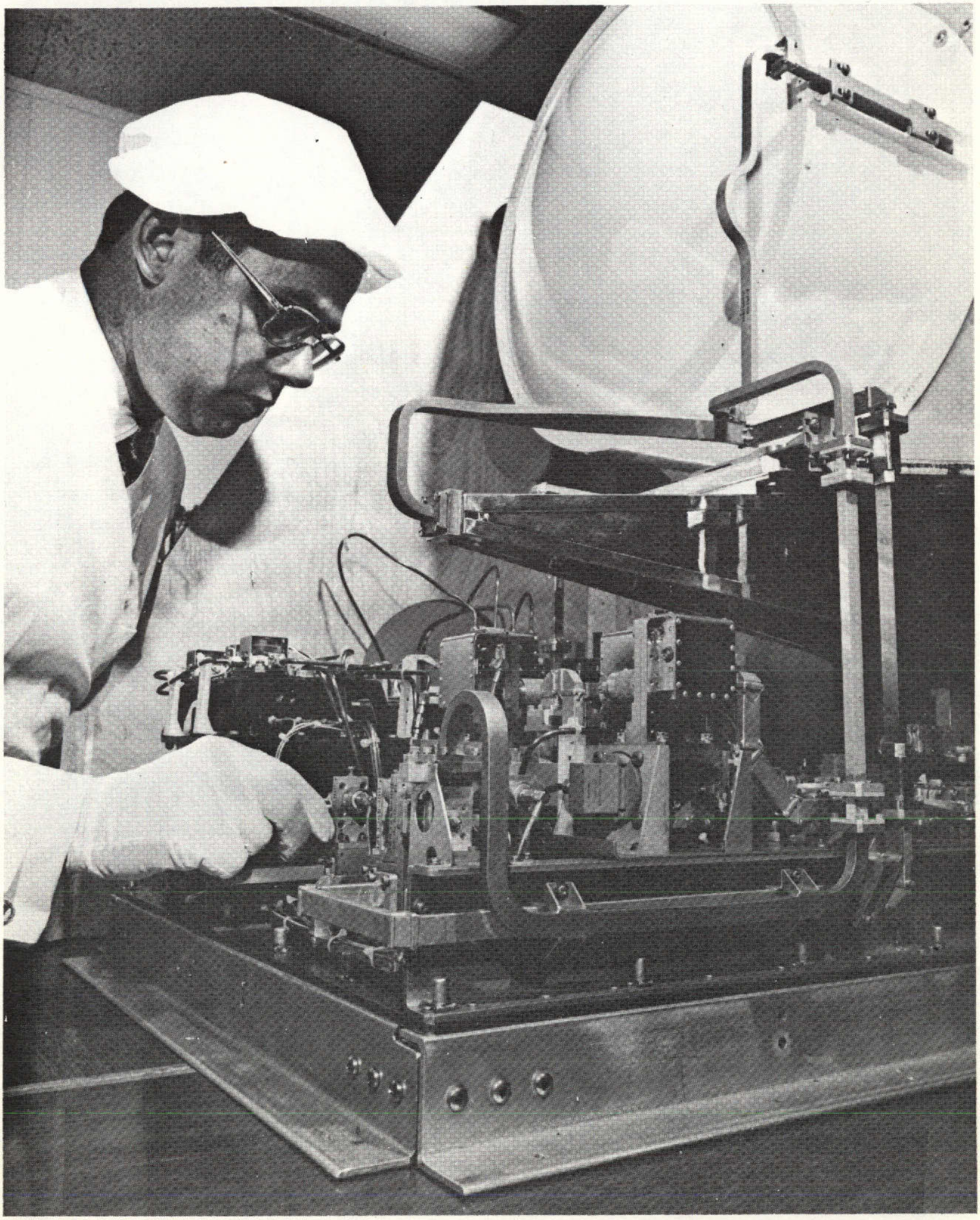


FIGURE 2-24. EXPERIMENT MOUNTED ON MOCKUP SIMULATING SPACECRAFT INSTALLATION (PHOTO 4S09085)

TABLE 2-21. INTERFACE CONTROL DRAWINGS FOR EXPERIMENT CONTROL ITEMS

Control Item	GSFC ICD Drawing
Composite experiment	G-460F-022
RF multiplier	G-460F-023
20/30 GHz modulator/power amplifier	G-460F-024
20/30 GHz parabolic antenna	G-460F-025
20/30 GHz horn antennas	G-460F-026
Thermal cover, 20/30 GHz parabolic antenna	G-460F-030
Thermal cover, 20/30 GHz horn antennas	G-460F-090
Drill Templates	
RF multiplier	GATS-460-091
Modulator/amplifier	GATS-460-092
Parabolic antenna	GATS-460-093
Horn antenna and horn antenna thermal cover	GATS-460-094
Parabolic antenna thermal cover	GATS-460-095

The parabolic antenna is cylindrical in shape with the end away from the radiating aperture being a paraboloid of revolution. Its diameter, exclusive of mounting flange, is about 18-1/2 inches and its height is about 12 inches. It is mounted to the inside of the earth viewing face by three No. 10-32 screws.

The horn antenna unit is irregular in shape but its maximum dimensions are approximately 12 inches long by 7-1/2 inches wide by 22 inches high. It is mounted by three No. 10-32 screws to the inside of the earth viewing surface.

The thermal cover for the parabolic antenna, a disk about 20 inches in diameter by about 3/10 inch thick, is mounted on the outside of the earth viewing surface with 16 No. 8-32 nonconductive screws.

The thermal cover for the horn antennas, an item about 12 inches long by about 7-1/2 inches wide by about 2/10 inch thick, is mounted on the outside of the earth viewing surface by 14 No. 8-32 nonconductive screws.

All mounting holes were drilled using templates which were subsequently shipped to the spacecraft contractor for locating matching holes or inserts in the spacecraft.

Alignment

Provisions have been made for aligning the antenna axes to the spacecraft axes. The E-field vector of the antennas must be aligned with the north-south axis of the spacecraft, but the accuracy of this alignment need not be precise. Location of mounting holes using the drill templates and normal shop practices for orienting them is entirely adequate. However, alignment of the electrical axes of the antennas to the earth pointing axis of the spacecraft must be more carefully done particularly in the case of the parabolic antenna which has a beamwidth of only 1.6 degrees at 30 GHz. During installation on the spacecraft, it may be necessary to install shims under one or two mounting points of each antenna to position the electrical boresight axis of the antennas parallel to the spacecraft earth pointing axis. Determination of alignment may be done optically using the alignment mirrors which are attached to each antenna. The optical axis of each of these mirrors has a known relationship to the electrical boresight of its respective antenna.

Weight

The original maximum weight requirement for the experiment was 85 pounds. Subsequent to the establishment of this requirement a number of changes were made to other experiment requirements which added hardware not originally contemplated. Some of these changes were substitution of a recessed parabolic antenna in place of two horn antennas, addition of antenna thermal covers as separately installed items, addition of COMSAT filters, and addition of LIC cross-connection provisions. Despite weight reduction efforts the total weight of the experiment increased to slightly over 90 pounds. The weights of the various components of the experiment are given in Table 2-22.

Thermal

The electronic subsystem of the experiment has been designed to operate properly with only conductive heat paths to the spacecraft cold walls. The mounting surfaces of the two units which dissipate essentially all the power have a flatness within ±0.010 in/ft and a No. 32 or better finish. In addition it is expected that a thermal bonding compound will be used between the modulator/power amplifier and the coldwall when it is installed in the spacecraft. To provide additional thermal stability, the high heat dissipating components, such as the TWT s, power supplies, RF multiplier unit, and miscellaneous amplifiers and regulators on the modulator/power amplifier, are coated with a high emissivity black paint. The thermal dissipation of the two units in the various operating modes is given in Table 2-23.

The parabolic antenna will be mounted in a well in the spacecraft which is thermally insulated from the interior of the earth viewing module. It will therefore see greater extremes of temperature than internally mounted components. To minimize the temperature extremes a multilayer Kapton cover is placed over the antenna aperture. Three layers of 1 mil Kapton are

TABLE 2-22. EXPERIMENT WEIGHT SUMMARY

Component	Weight, pounds
RF multiplier	14.3
Modulator/power amplifier	62.4
Parabolic antenna	6.6
Horn antennas	4.3
Thermal cover, parabolic antenna	0.8
Thermal cover, horn antennas	0.2
COMSAT filters	0.7
Miscellaneous interconnecting coax cable, waveguides, and hardware	2.1
Total Experiment	91.4

used, each with 1.5 mils of gloss white paint on one side. The painted side of the two inner sheets faces outboard, and the painted side of the outer sheet faces inboard. Reversal of the outer sheet permits the Kapton to act as an ultraviolet absorber and minimizes changes in solar absorptivity during mission life. The surfaces of the parabolic reflector and tunnel that face outboard are highly polished for minimum emittance. An analysis has been performed of the antenna as installed and the maximum and minimum temperatures expected on the reflector and on the feed are given in Table 2-24. Also given in Table 2-24 is the expected heat leak into and out of the EVM due to the parabolic antenna.

The horn antennas will be mounted within the temperature controlled environment of the EVM, but the lips of the horns will pass through the thermal insulation. To minimize the temperature extremes on the horns and to minimize the EVM heat leak, a Kapton thermal cover of the same type as for the parabolic antenna is placed over the horn antenna apertures. In addition all surfaces of the horn antenna assembly are coated with vacuum deposited aluminum for minimum emittance. An analysis has been performed of the horn antennas as installed in the spacecraft, and maximum and minimum temperatures expected on the antennas and expected heat leaks are given in Table 2-25.

TABLE 2-23. THERMAL DISSIPATION OF ELECTRONIC SUBSYSTEM FOR VARIOUS OPERATING MODES

Operating Mode	Thermal Dissipation, watts	
	RF multiplier	Modulator/ power amplifier
LIC power only applied	0	0.7
Master oscillator only ON	1.9	0.8
Master oscillator and multiplier only ON	16.0	1.8
Full operation 20 GHz only in CW mode	16.0	20.5
Full operation 20 GHz only in MT mode	16.0	22,5
Full operation 20 GHz only in COMM mode	16.0	23.2*
Full operation 30 GHz only in CW mode	16.0	27.8
Full operation 30 GHz only in MT mode	16.0	22.8
Full operation 30 GHz only in COMM mode	16.0	30.5*
Full operation 20/30 GHz in CW mode	16.0	47.5
Full operation 20/30 GHz in MT mode	16.0	49.5
Full operation 20/30 GHz in COMM mode	16.0	50.2*

*If VCO is used 1.0 watt must be added.

TABLE 2-24. THERMAL PREDICTIONS FOR PARABOLIC ANTENNA

Condition	Reflector Temperature, ^{o}F		Average Feed Temperature, ^{o}F		Thermal Leakage, watts	
	Min.	Max.	Min.	Max.	Min.	Max.
No sun	-13	-10	12	52	-0.9	-1.1
With sun (beginning of life)	107	124	78	114	+0.5	+0.9
With sun (after 2 years in orbit)	135	151	96	132	+1.0	+1.3

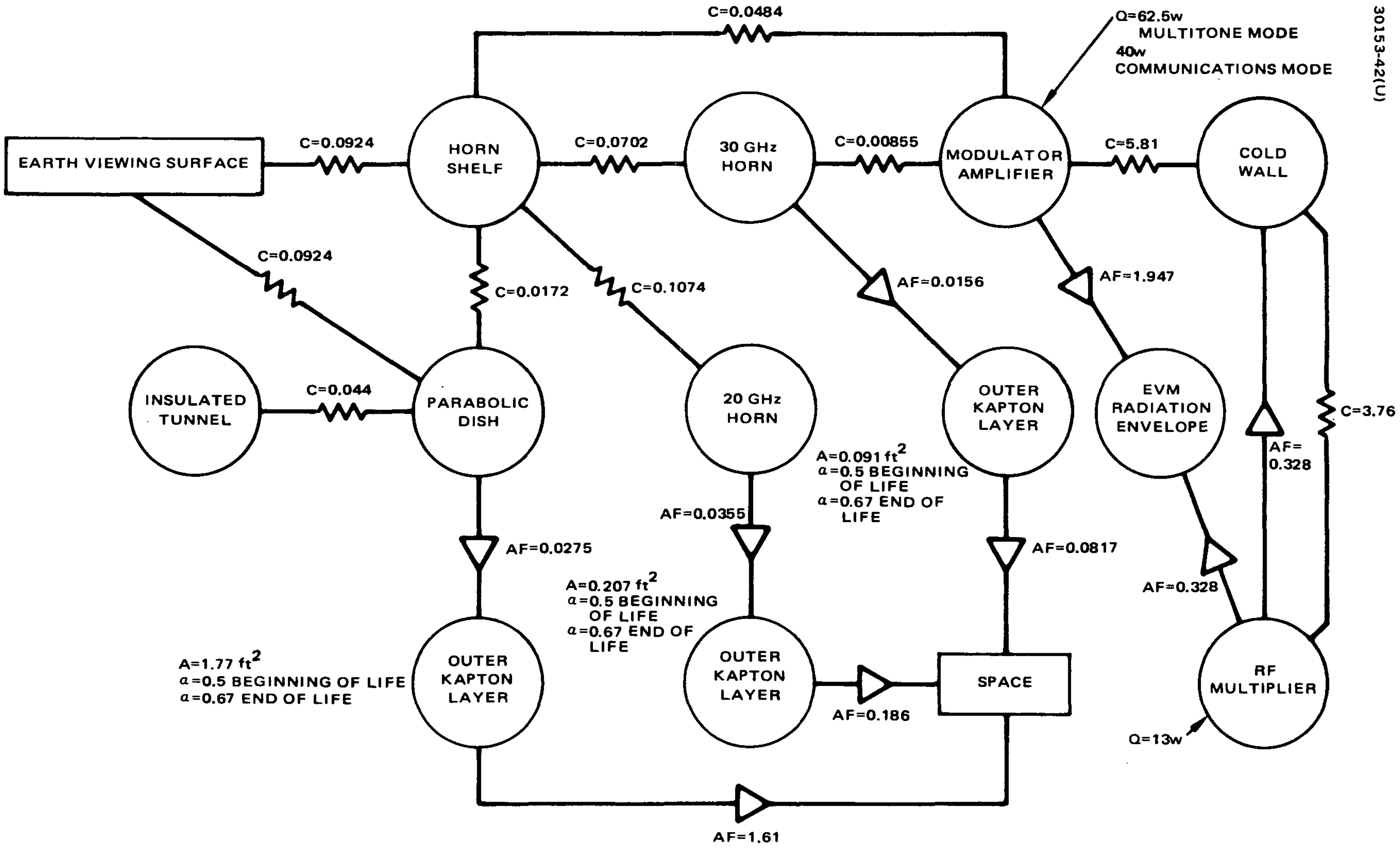


FIGURE 2-25. MILLIMETER WAVE EXPERIMENT ANALYTICAL THERMAL MODEL

TABLE 2-25. THERMAL PREDICTIONS FOR HORN ANTENNAS

Condition	20 GHz Horn Temperature, °F		20 GHz Horn Thermal Leakage, watts		30 GHz Horn Temperature, °F		30 GHz Horn Thermal Leakage, watts	
	Min.	Max.	Min.	Max.	Min.	Max.	Min.	Max.
No sun	30	65	-1.2	-1.6	36	74	-0.6	-0.8
With sun (beginning of life)	67	100	+0.9	+1.4	63	98	+0.4	+0.6
With sun (after 2 years in orbit)	78	109	+1.6	+2.1	71	105	+1.0	+1.1

An analytical thermal model for the complete experiment was prepared and then reduced to a manageable number of nodes. The model, which is shown in Figure 2-25, was supplied to GSFC for inclusion in the overall spacecraft thermal model.

Structural Dynamics

Although structural analyses were performed during the design stages to ensure that the experiment hardware would survive the qualification and launch environments, a few problems were revealed during qualification vibration tests. These problems are as follows:

1) Structural failure of the feed waveguide on the parabolic antenna

2) Structural failure of mounting flanges on the X9 multiplier module and the beginning of a similar failure on the X10 multiplier module, both in the RF multiplier unit

3) Structural failure of a waveguide bracket on the modulator/power amplifier

4) Bond joint failures in several brackets supporting waveguides or cables in the modulator/power amplifier

5) Failure of several semirigid coax cables in the RF multiplier and modulator/power amplifier

For the first four of these problems, redesign and rework were accomplished. In the case of the coax problems, rerouting and additional supports were incorporated. Subsequent retest to modified qualification level profiles verified the adequacy of the redesigns.

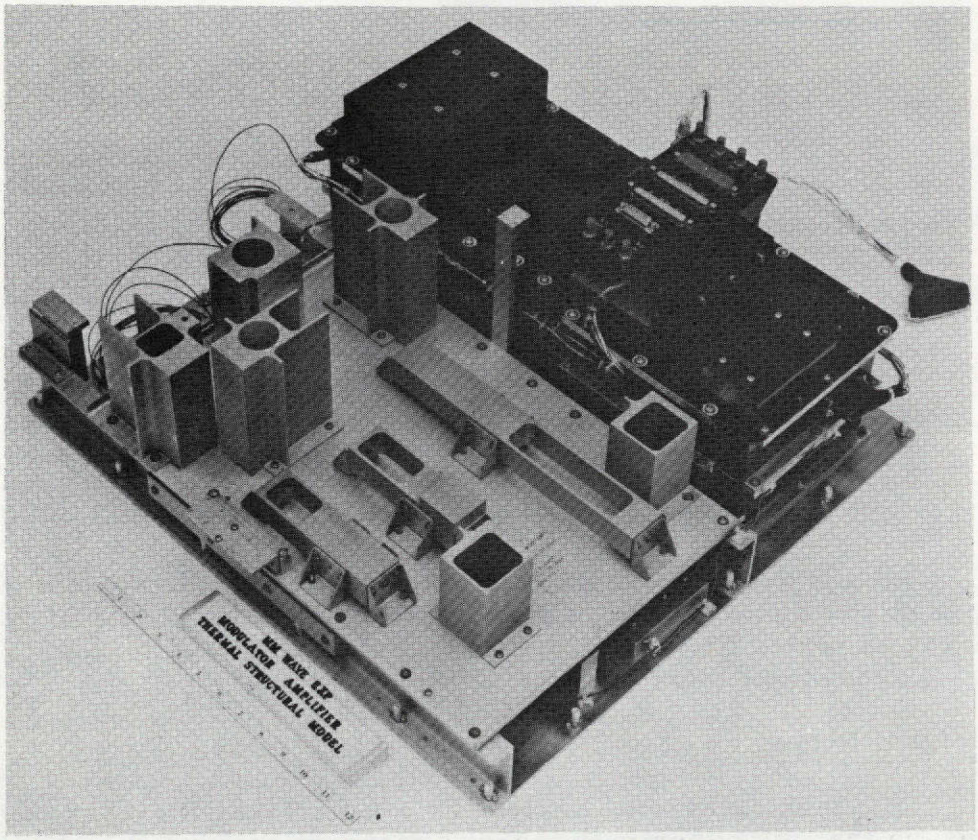


FIGURE 2-26. THERMAL STRUCTURAL MODEL MODULATOR/POWER AMPLIFIER (PHOTO 4R22220)

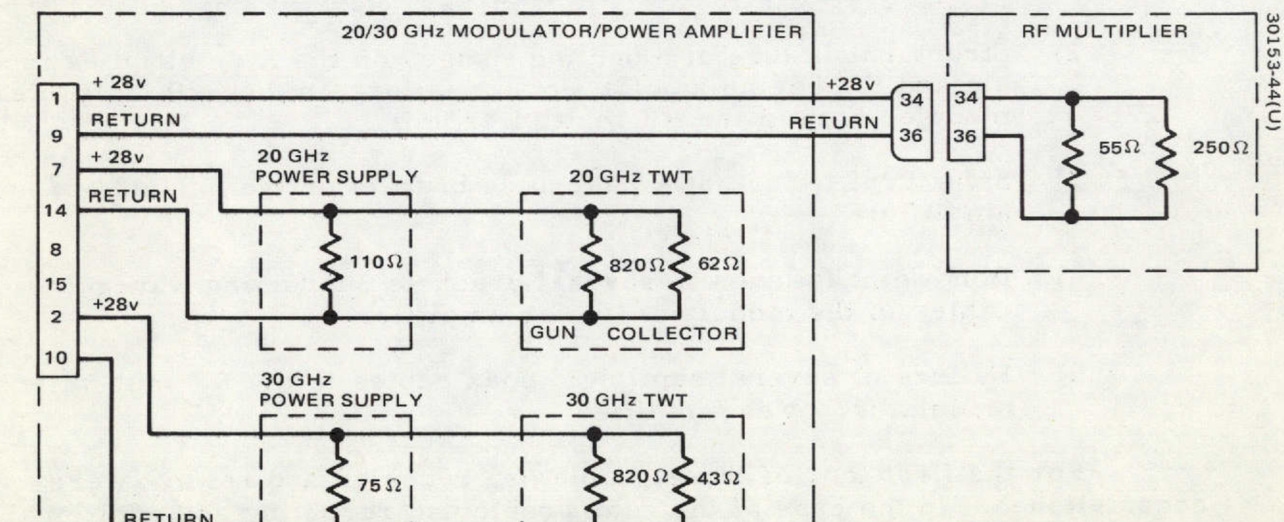


FIGURE 2-27. THERMAL STRUCTURAL MODEL SCHEMATIC DIAGRAM

With one exception, no mechanical resonances of any of the hardware below 100 Hz was noted during the tests. The one exception is the master oscillator which is shock mounted to protect the crystal. The natural frequency of the shock mount was made intentionally low since experience with an identical unit on a previous program indicated it would survive only with this type of shock mounting. An additional case of low frequency resonance was predicted by analysis. This was the main deck of the modulator/power amplifier which was made of a thinner material than would be required to raise the resonant frequency. However, by making use of the structural characteristics of the spacecraft coldwall, the combined dynamic response is satisfactory. Testing of the modulator/power amplifier was done with a 1/2 inch thick honeycomb panel as an intermediate structure between the vibration table and the unit in an attempt to simulate the combination of the unit and spacecraft panel.

Thermal Structural Model

A thermal structural model (TSM) of the experiment was constructed and delivered to the spacecraft contractor for thermal and vibration testing of a TSM spacecraft. The antennas delivered as part of the TSM were engineering models essentially built to the final drawings. The electronic units contained mass models of the modules but the mechanical interface and outline dimensions were the same as for the flight model. A photograph of the TSM modulator/power amplifier is shown in Figure 2-26.

Thermal simulation in the TSM electronic units consisted of fixed resistors at strategic locations in the units which, when connected to an external 28 Vdc supply, would dissipate the same power as the flight model. Four thermal dissipation conditions could be simulated as indicated on the schematic of Figure 2-27. These conditions, with the total power dissipation for each, are listed below.

1) All electronics ON except the TWTAs 19.5 watts

2) All electronics and a 20 GHz TWTA ON 39.2 watts

3) All electronics and a 30 GHz TWTA ON 46.5 watts

4) All electronics and both TWTAs ON 66.2 watts

REFERENCES

2-1. Hewlett-Packard Application Note No. 7, Computer Counter Applications Library, "Fractional Frequency Deviation"

2-2. Hughes Interdepartmental Correspondence from J. A. Caird, dated 14 September 1970, "Master Oscillator Test - Millimeter Wave Experiment"

3. UNIT DESCRIPTION AND PERFORMANCE

INTRODUCTION

This section describes in some detail the various units which make up the complete experiment and records the performance which was achieved in the flight prototype model of these items. In general, performance features which were covered in the system description (Section 2) will not be repeated here. Discussed in turn in this section are the RF multiplier unit, the 20/30 GHz modulator/power amplifier unit, the 20/30 GHz horn antennas, the 20/30 GHz parabolic antenna, and the COMSAT filters.

RF MULTIPLIER UNIT

The RF multiplier unit serves as the basic source of RF energy for the experiment. As shown in the block diagram of Figure 3-1, it contains the master oscillator and multiplier chains and provides redundant 180 MHz and 10 GHz signals for the 20/30 GHz modulator/power amplifier. The photograph of Figure 3-2 shows the completed flight/prototype model, and the photograph of Figure 3-3 shows the same model with the cover removed to reveal some of the modules it contains. The unit weighs 14.3 pounds and overall dimensions are approximately 14.5 inches by 8.9 inches by 7.0 inches. More detail on the configuration may be found on the RF multiplier interface control drawing (Reference 3-1).

Each of the redundant 10 GHz outputs of the RF multiplier is supplied to the modulator/power amplifier through a semirigid coaxial cable at a level of about 500 mw. Similarly each 180 MHz signal is supplied through semirigid coaxial at a level of about 10 mw. At 28 volt dc spacecraft bus level the total dc power applied to the RF multiplier is about 16.5 watts for a total dissipation within the unit of 16 watts. Dc power, command signals, and telemetry signals are carried through a single 37 pin connector on the unit and specific pin connections for each function are shown on Table 3-1. More detail on electrical connections in the unit are given on the interconnection diagram (Reference 3-2).

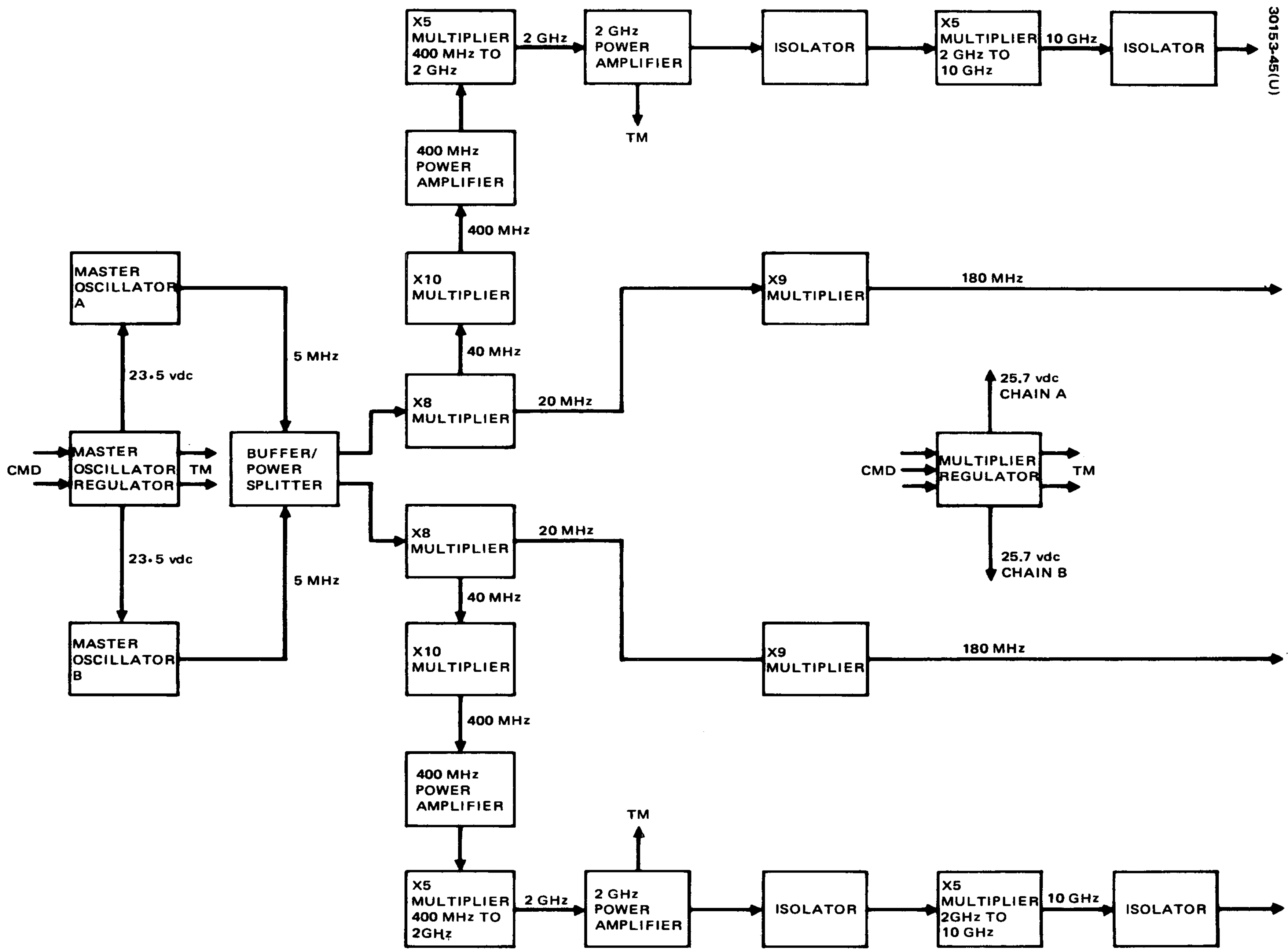


FIGURE 3-1. RF MULTIPLIER UNIT BLOCK DIAGRAM

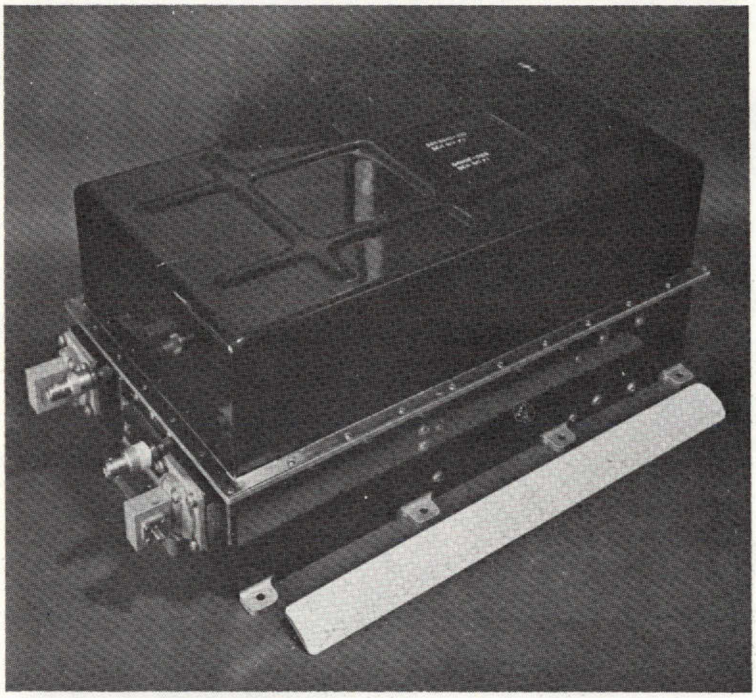


FIGURE 3-2. RF MULTIPLIER UNIT FLIGHT/PROTOTYPE MODEL (PHOTO A33312)

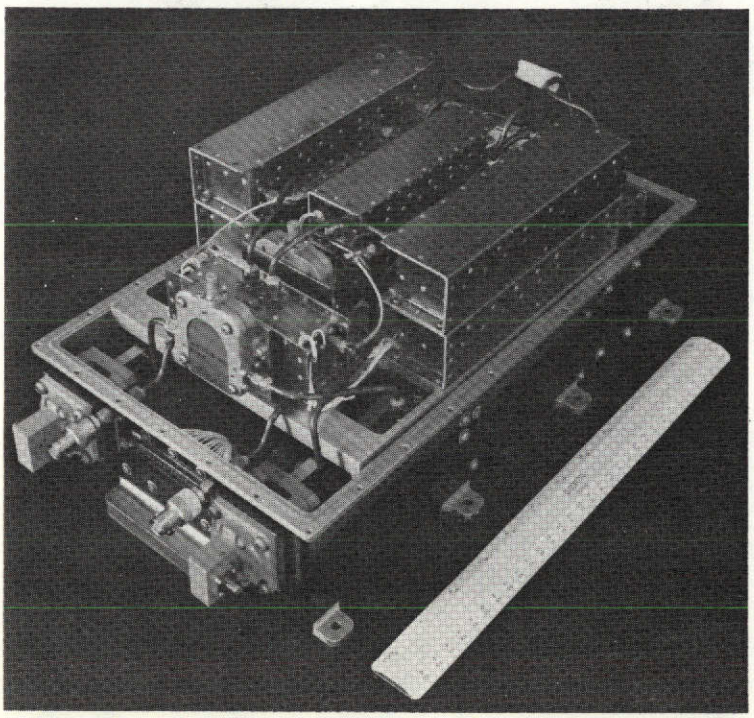


FIGURE 3-3. RF MULTIPLIER UNIT WITH COVER REMOVED (PHOTO 30153-47)

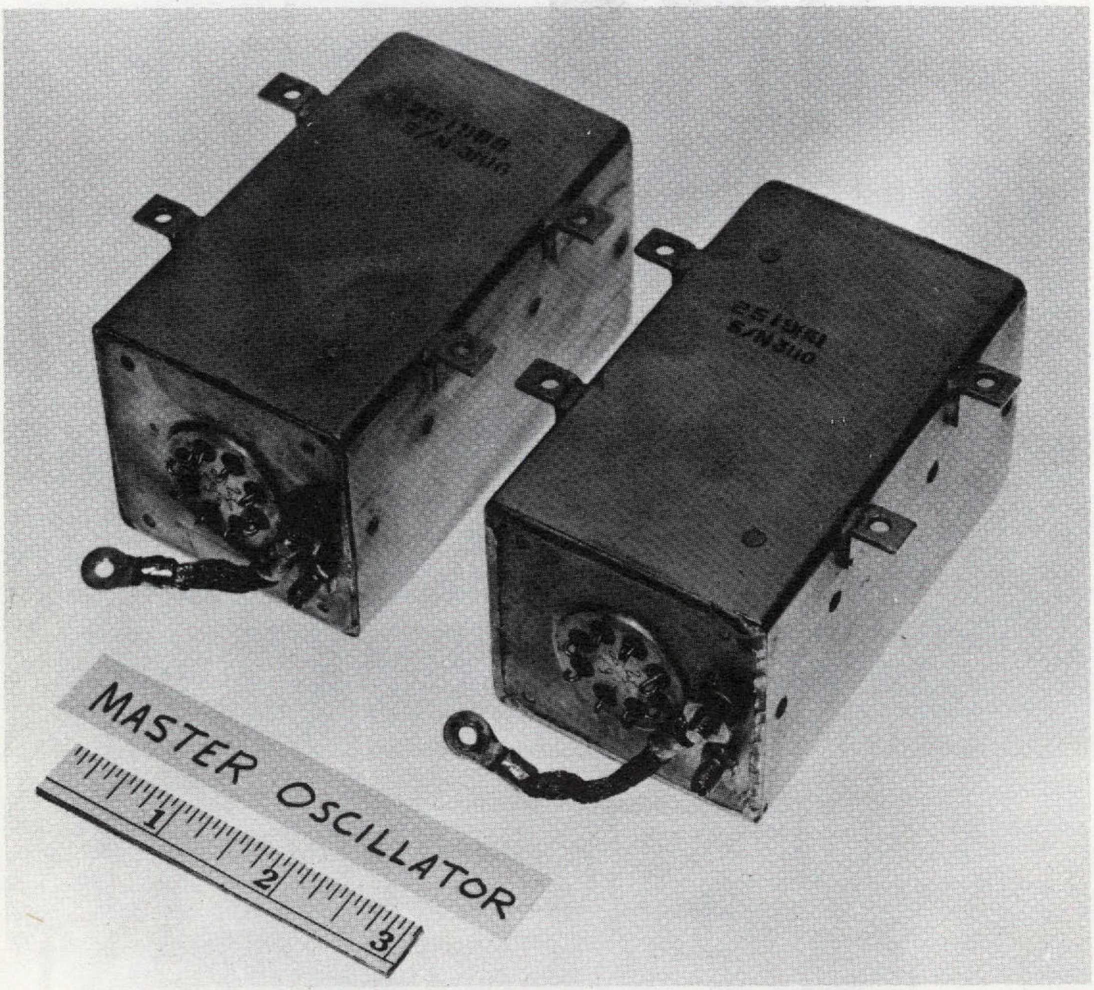


FIGURE 3-4. 5 MHz MASTER OSCILLATOR (PHOTO 4R18253)

TABLE 3-1. PIN CONNECTIONS ON RF MULTIPLIER CONNECTOR 310J1

Description	Pin No.
Master oscillator A ON command	1, 2
Master oscillator B ON command	3, 4
Multiplier chain A ON command	5, 6
Multiplier chain B ON command	7, 8
Multiplier chains OFF command	9, 10
Command return	26, 27
Master oscillator A bilevel telemetry	15, 16
Master oscillator B bilevel telemetry	17, 18
Multiplier chain A bilevel telemetry	11, 12
Multiplier chain B bilevel telemetry	13, 14
Telemetry return, bilevel	28, 19
2 GHz power monitor A telemetry	19, 20
2 GHz power monitor B telemetry	21, 22
Telemetry return, analog	30, 31
Dc power bus	34, 35
Dc power return	36, 37

Master Oscillator

Each of the two redundant master oscillators is contained in a drawn aluminum can housing as shown in Figure 3-4. The oscillator uses a fundamental mode crystal at 5 MHz, housed in a proportional temperature controlled oven maintained at 160°F. The inflection point of the crystal was chosen for the minimum thermal coefficient of frequency change at 160°F. After the temperature of the oven has stabilized at the 160°F operating level, the frequency of the oscillator is within ±10 Hz of the nominal 5 MHz, and the short term stability is better than two parts in 10^{10} averaged over 10 ms. Long term drift of the oscillator is expected to be better than one part in 10^7 per year.

Buffer/Power Splitter

The +2 dBm, 5 MHz signal from the oscillator is amplified in the buffer amplifier. This amplifier incorporates discrete components with soldered interconnections that are foamed in place inside the chassis shown in Figure 3-5. A power splitter provides two outputs from the amplifier. One +7 dBm output is applied to each of the two redundant multiplier chains. Each output has harmonically related spurious responses that are 24 dB below the 5 MHz output signal. The amplifier swept out response is shown in Figure 3-6.

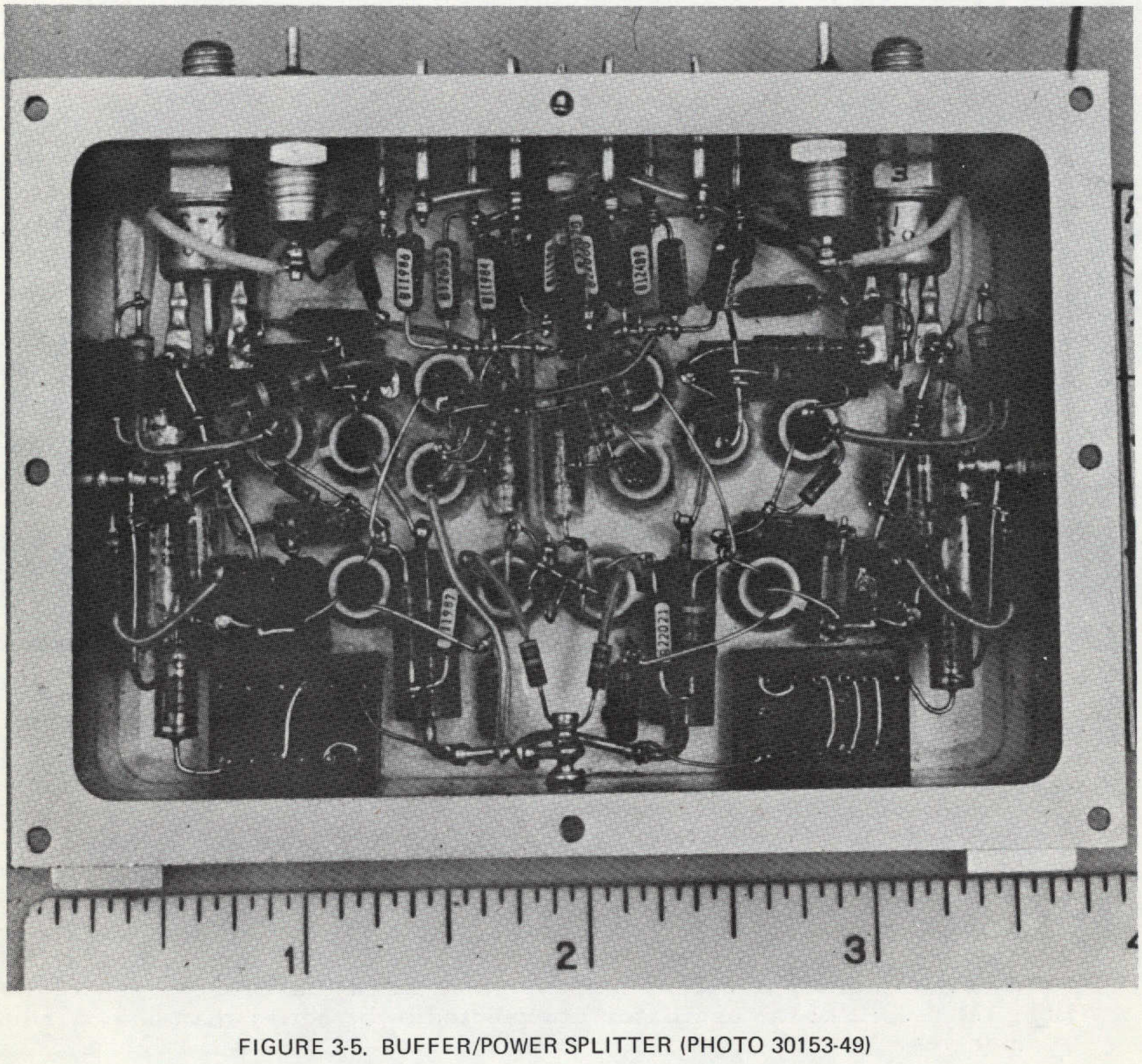


FIGURE 3-5. BUFFER/POWER SPLITTER (PHOTO 30153-49)

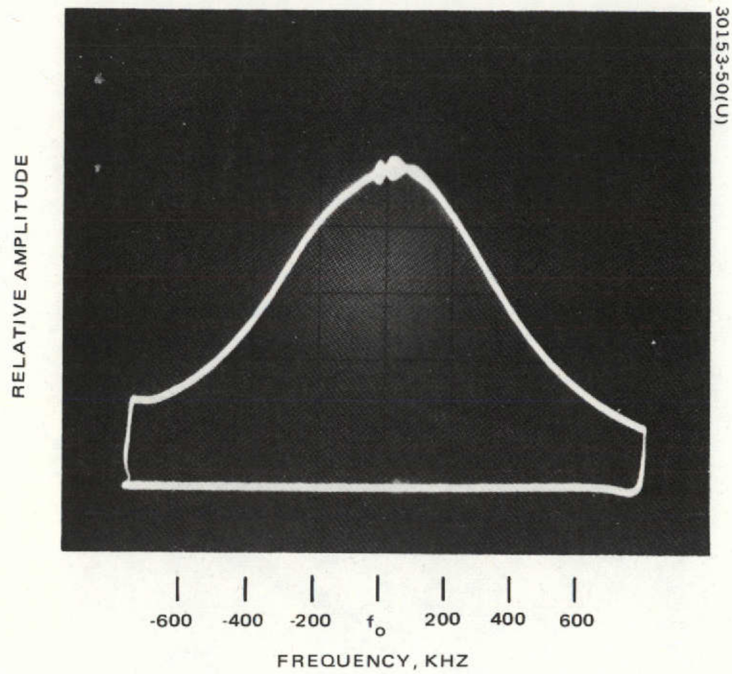


FIGURE 3-6. BUFFER/POWER SPLITTER SWEPT FREQUENCY AT ROOM TEMPERATURE

X8 Multiplier

The first step in each multiplier is the X8 multiplier. This electronic module incorporates discrete components with soldered interconnections that are foamed in place inside the wrap around chassis shown in Figure 3-7.

The module consists of three transistor X2 multipliers in tandem with two outputs. One output is a 6.7 dBm 20 MHz signal resulting from the first two X2 multipliers. It has harmonically related spurious responses 32 dB below the 20 MHz output signal. The second output is a 7.9 dBm, 40 MHz signal resulting from the last X2 multiplier. It has harmonically related spurious responses 50 dB below the 40 MHz output signal. The X8 multiplier swept 20 MHz and 40 MHz output responses are shown in Figure 3-8.

X9 Multiplier

The 20 MHz signal is applied to the X9 multiplier module, which consists of two transistor X3 multipliers in tandem. This module incorporates discrete components with soldered interconnections that are foamed in place inside the wraparound chassis shown in Figure 3-9. The 10.8 dBm 180 MHz output signal is at least 50 dB greater than any harmonically related spurious responses and represents an output of the RF multiplier unit. When connected to the modulator/power amplifier unit, the signal is further amplified and then provides the VHF multitone modulation. The X9 multiplier swept output response is shown in Figure 3-10.

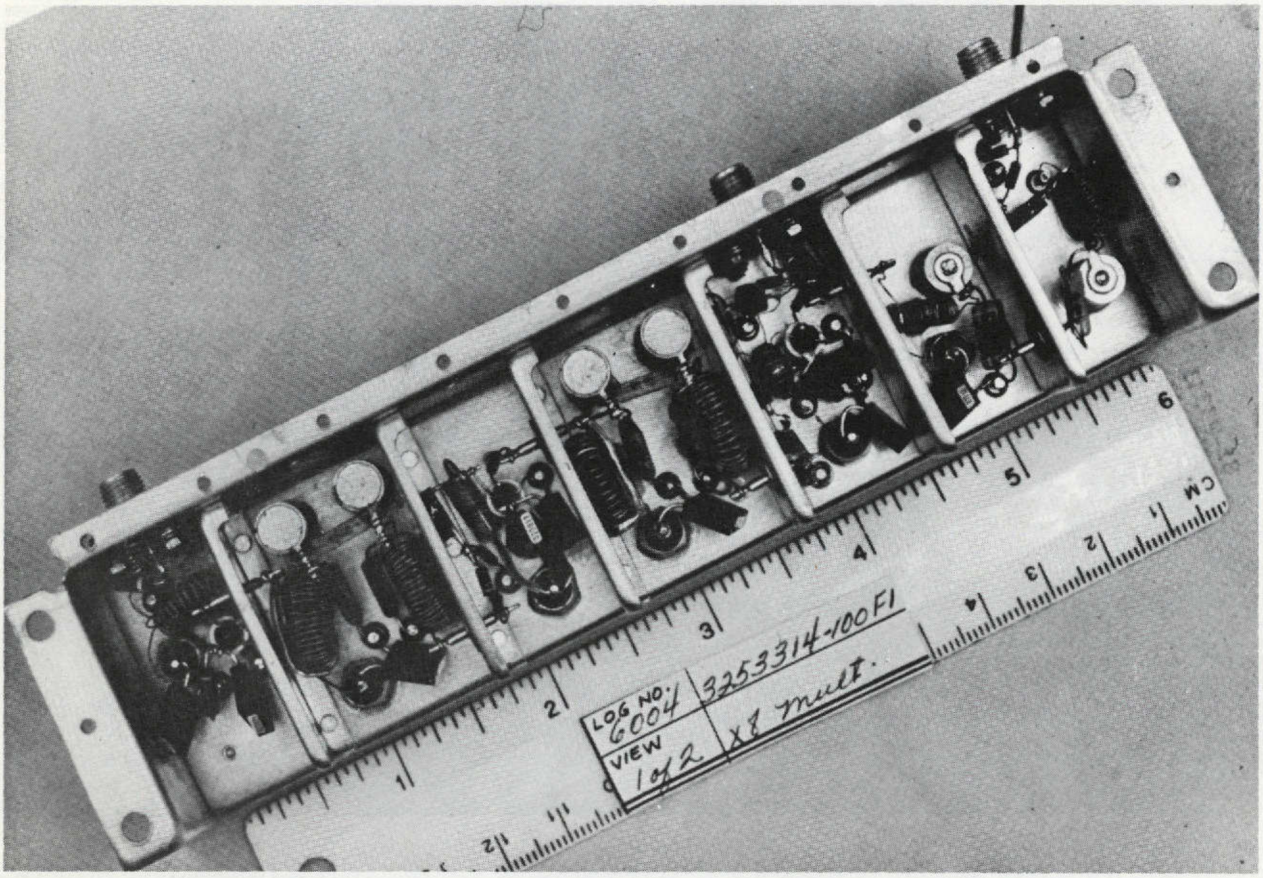


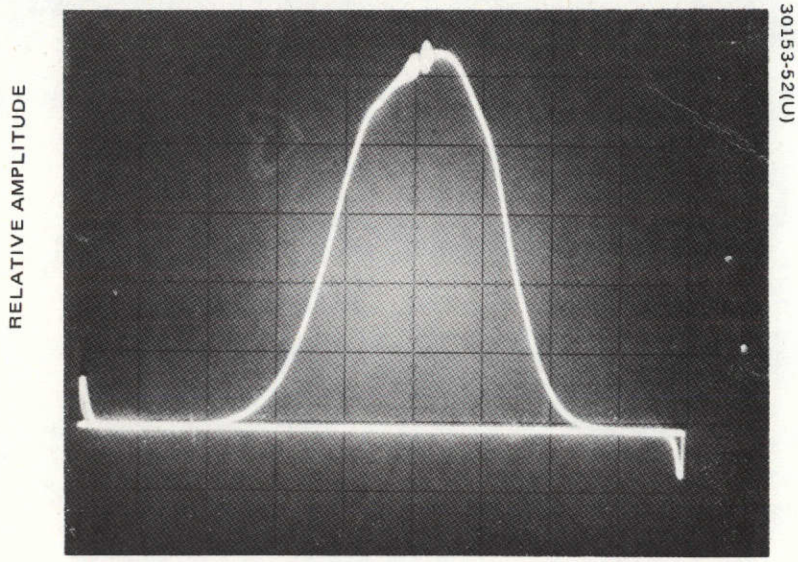
FIGURE 3-7. X8 FREQUENCY MULTIPLIER (PHOTO 30153-51)

X10 Multiplier

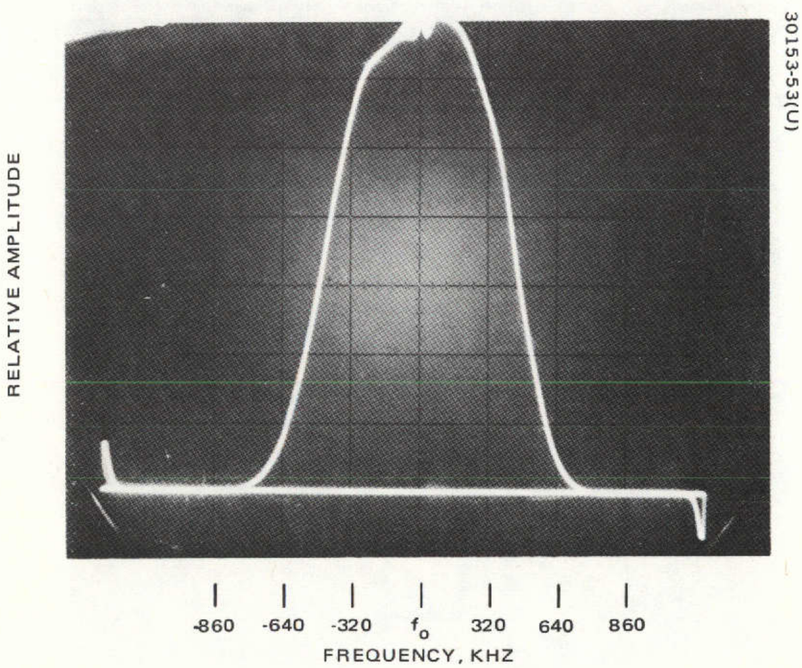
The 40 MHz signal out of the X8 multiplier is applied to the X10 multiplier module where it is multiplied to 400 MHz by means of a single step, varactor diode multiplier and amplified in two transistor stages. The module incorporates discrete components with soldered interconnections that are foamed in place inside the wrap around chassis shown in Figure 3-11. The X10 multiplier swept output response is shown in Figure 3-12. The +14.7 dBm, 400 MHz signal is 34 dB greater than any harmonically related spurious responses.

400 MHz Power Amplifier

The 400 MHz signal is applied to the two transistor, 400 MHz power amplifier module. This amplifier incorporates discrete components with soldered interconnections that are foamed in place inside the milled out chassis shown in Figure 3-13. The 400 MHz amplifier asymmetrical swept output response, shown in Figure 3-14, is the result of the final stage transistor operating Class C and exhibiting a low frequency resonance in its input matching network. The resonance drastically reduces the input power to the transistor, effectively turning the amplifier off at the resonant fre-



a) 20 MHz OUTPUT



b) 40 MHz OUTPUT

FIGURE 3-8. X8 MULTIPLIER SWEPT FREQUENCY RESPONSE AT ROOM TEMPERATURE

quency, which is well below the amplifier's 400.0 ±25.0 MHz frequency band of operation. The amplifier was tuned in this manner to enable it to achieve its +30.8 dBm, 400 MHz output signal, which is 35 dB greater than any harmonically related spurious responses.

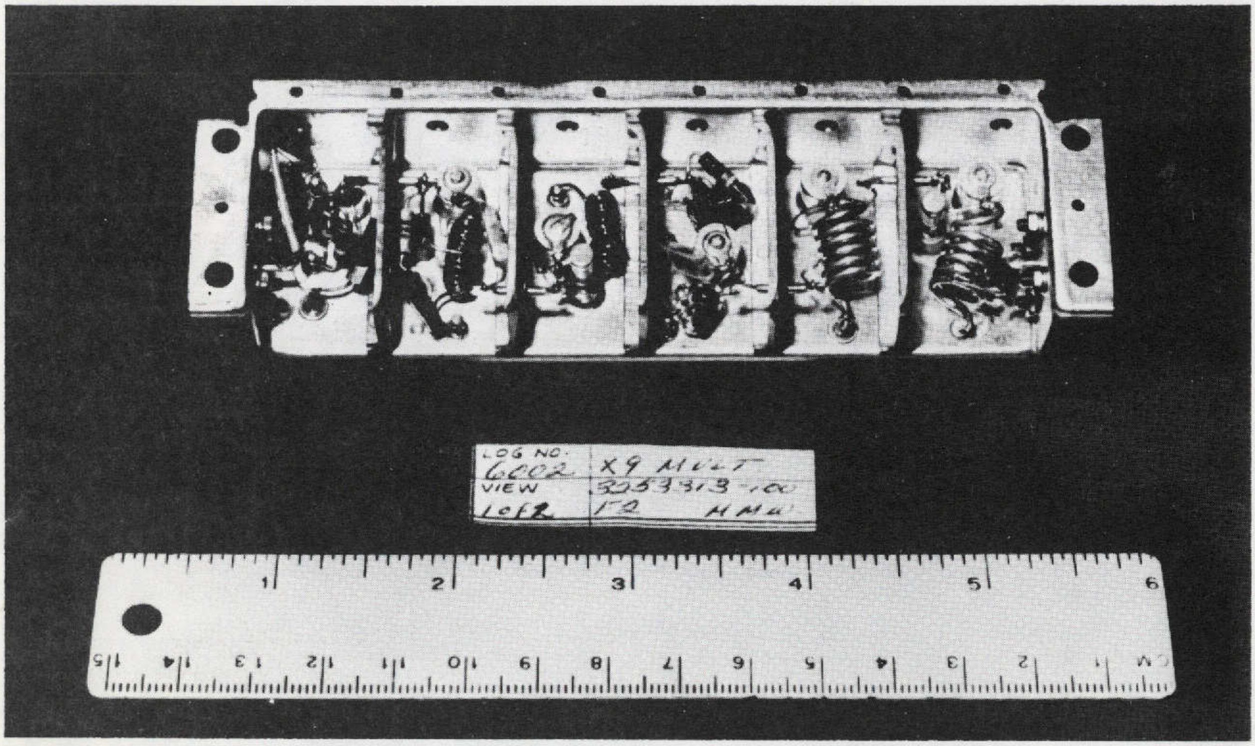


FIGURE 3-9. X9 FREQUENCY MULTIPLIER (PHOTO 30153-54)

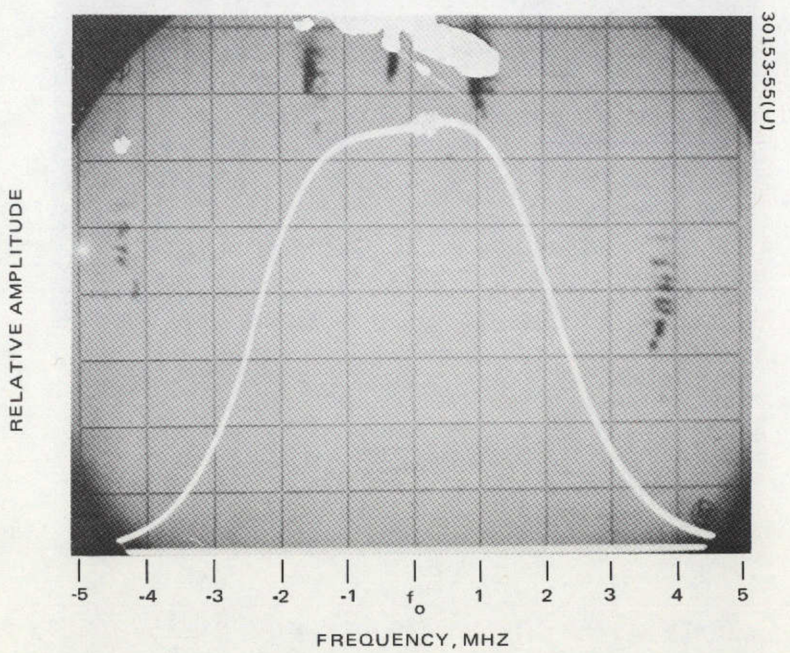


FIGURE 3-10. X9 MULTIPLIER SWEPT FREQUENCY RESPONSE AT ROOM TEMPERATURE

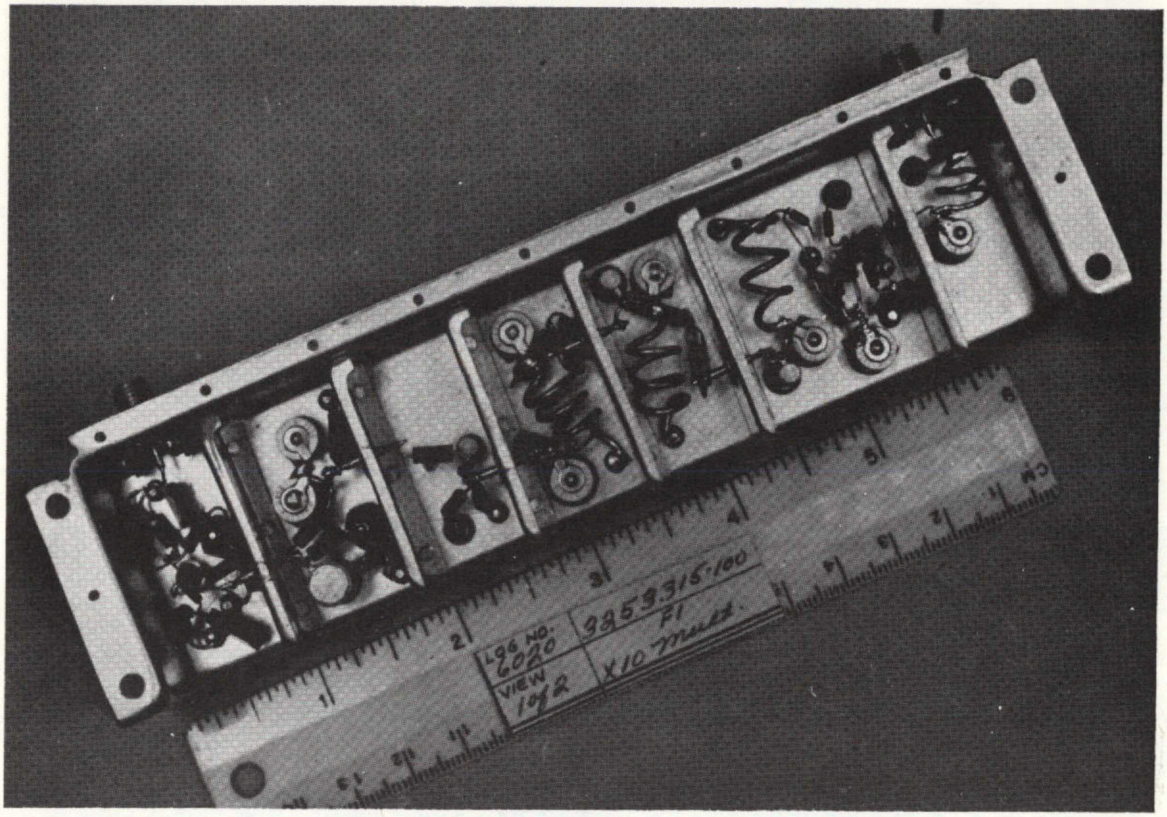


FIGURE 3-11. X10 FREQUENCY MULTIPLIER (PHOTO 30153-56)

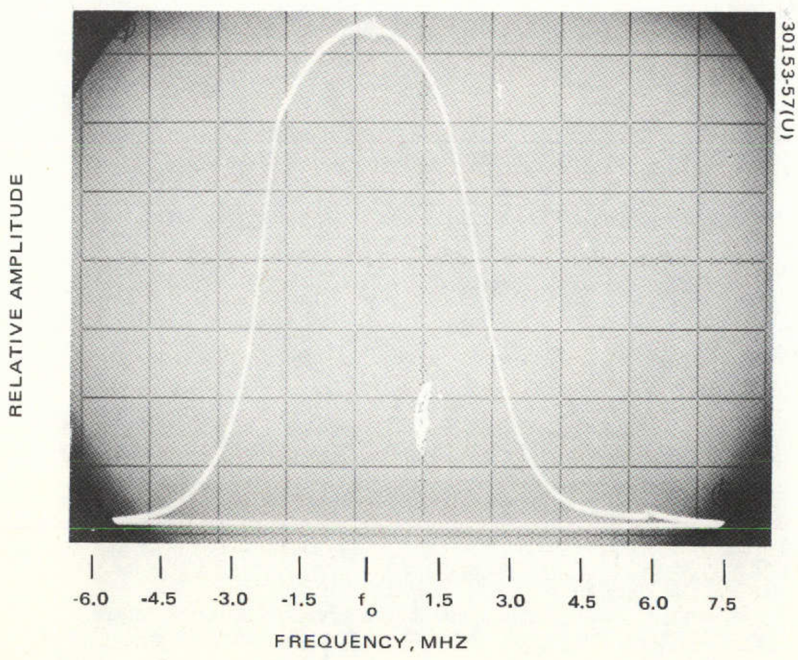


FIGURE 3-12. X10 MULTIPLIER SWEPT FREQUENCY RESPONSE AT ROOM TEMPERATURE

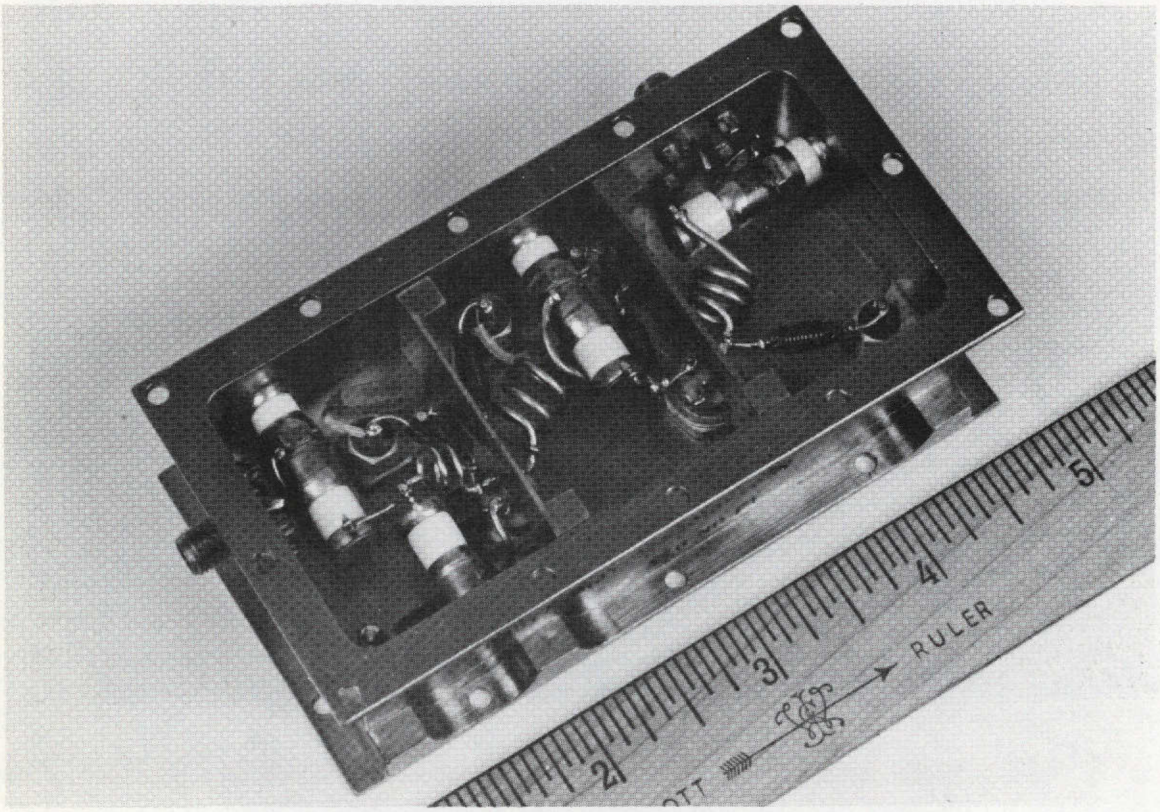


FIGURE 3-13. 400 MHz POWER AMPLIFIER (PHOTO 30153-58)

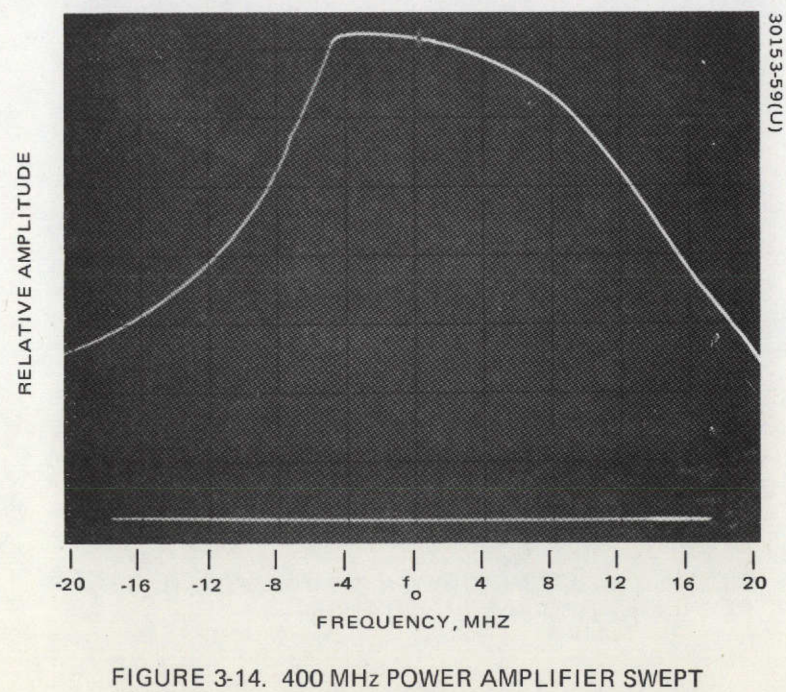


FIGURE 3-14. 400 MHz POWER AMPLIFIER SWEPT FREQUENCY RESPONSE AT ROOM TEMPERATURE

X5 Multiplier (400 MHz to 2 GHz)

The amplified 400 MHz signal is applied to the X5 multiplier (400 MHz to 2 GHz) module. It incorporates an HP-300 step recovery diode and a four section interdigital output filter contained inside the milled out chassis shown in Figure 3-15 and foamed in place. The module has an output swept response shown in Figure 3-16, and its +24.4 dBm, 2 GHz output signal is 50 dB greater than any harmonically related spurious responses.

2 GHz Power Amplifier

The signal from the X5 multiplier is applied to the 2 GHz power amplifier which incorporates discrete components with soldered interconnections that are foamed in place inside the milled out chassis shown in Figure 3-17. The 2 GHz amplifier asymmetrical swept output response, shown in Figure 3-18, is the result of its MSC-3003 microwave power transistor operating Class C and exhibiting a low frequency resonance in its input matching network. The resonance drastically reduces the input power to the transistor, effectively turning the amplifier off at the resonant frequency which is well below the amplifier 2.00 ±0.05 GHz frequency band of operation. The 2 GHz amplifier was tuned in this manner to enable it to achieve its high 33.9 dBm 2 GHz output power with 45 dB purity over harmonically related spurious responses and good stability across its frequency band over its operating range of temperature.

X5 Multiplier (2 GHz to 10 GHz)

After the 2 GHz signal passes through an isolator, final multiplication to 10 GHz occurs in the X5 multiplier (2 GHz to 10 GHz) module. This module utilizes a 2 GHz matching network consisting of a few discrete components with soldered interconnections that are foamed in place inside the lower portion of the milled out chassis shown in Figure 3-19. The waveguide upper structure of the chassis contains a 10 GHz bandpass filter with several capacitive turning screws and a sliding short. The 2 GHz input signal from the coaxial input port is matched by the input network to maximize the 2 GHz signal level applied to the multiplier HP-300 step recovery diode which enables it to generate a wide spectrum of frequencies. A dipole protruding from the diode holder in the matching network through the waveguide broadwall couples these higher harmonics into the waveguide structure where the 10 GHz bandpass filter eliminates the unwanted harmonics. The 10 GHz signal is passed through a waveguide isolator, through a waveguide to coaxial transition, and is then available at the output of the RF multiplier unit at a level of about +27 dBm.

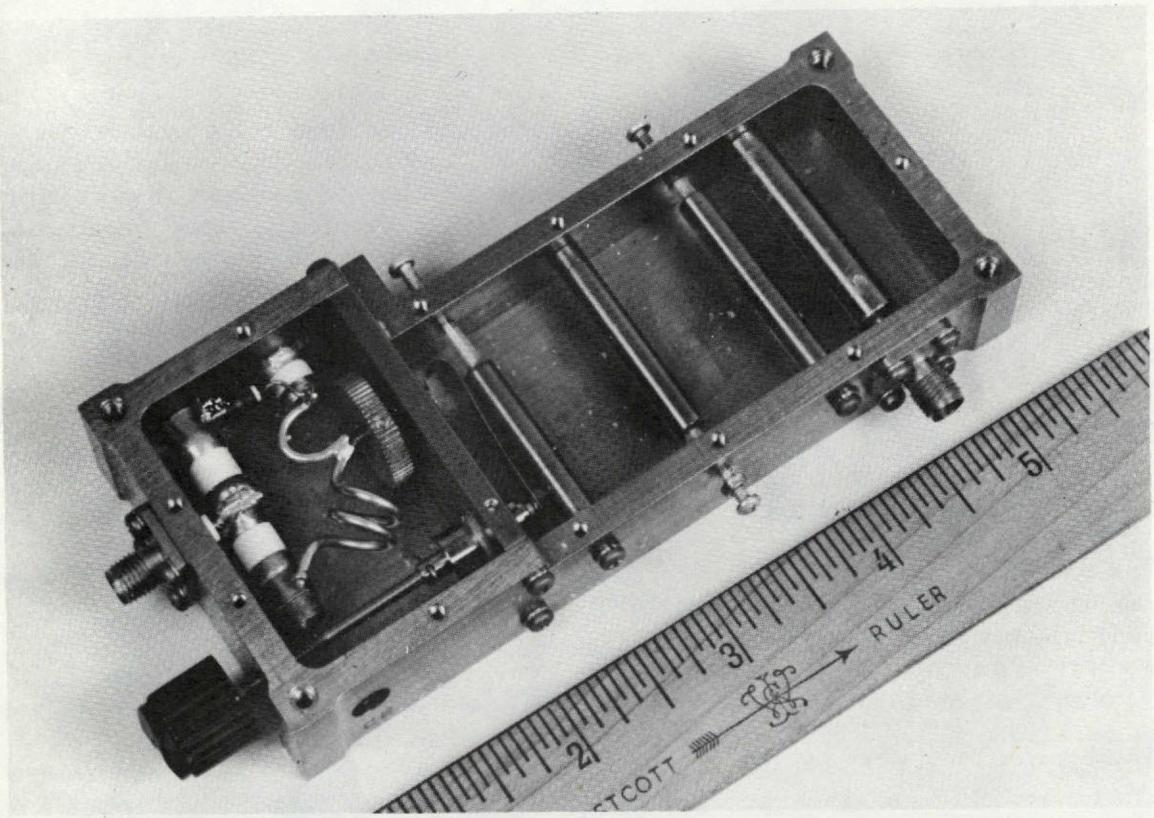


FIGURE 3-15. X5 FREQUENCY MULTIPLIER (400 MHz TO 2 GHz) (PHOTO 30153-60)

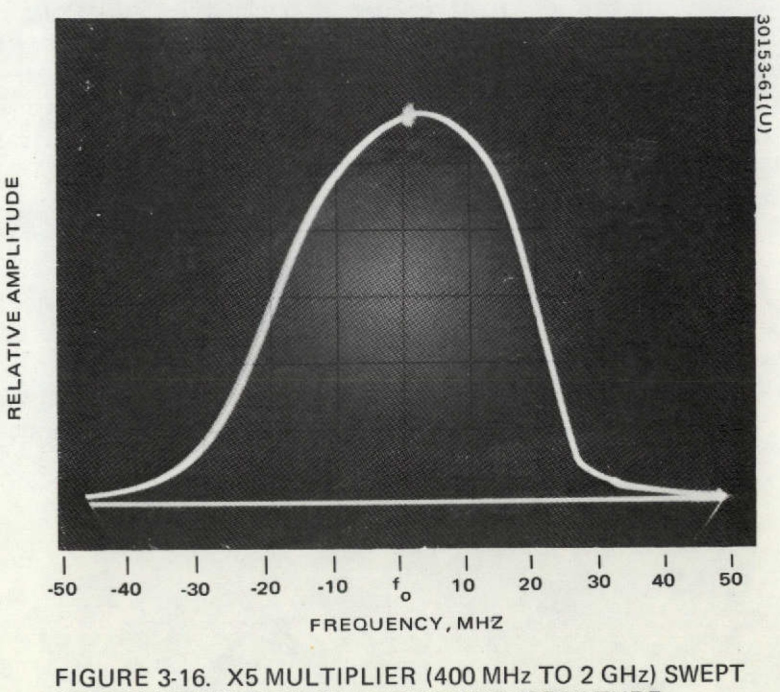


FIGURE 3-16. X5 MULTIPLIER (400 MHz TO 2 GHz) SWEPT FREQUENCY RESPONSE AT ROOM TEMPERATURE

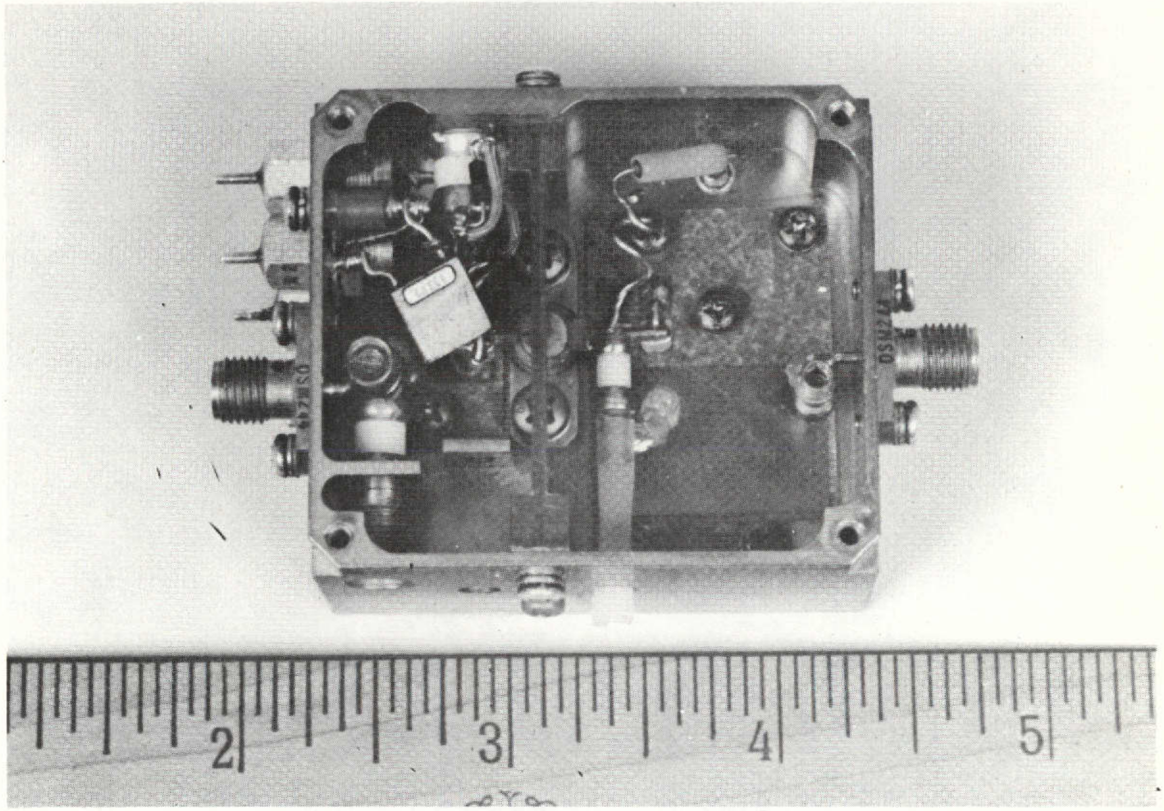


FIGURE 3-17. 2 GHz POWER AMPLIFIER (PHOTO 30153-62)

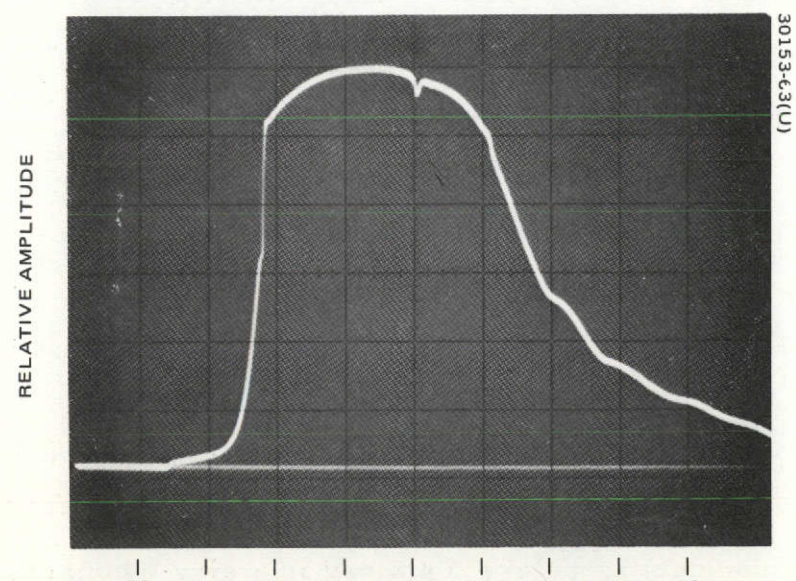


FIGURE 3-18. 2 GHZ POWER AMPLIFIER SWEPT FREQUENCY RESPONSE AT ROOM TEMPERATURE

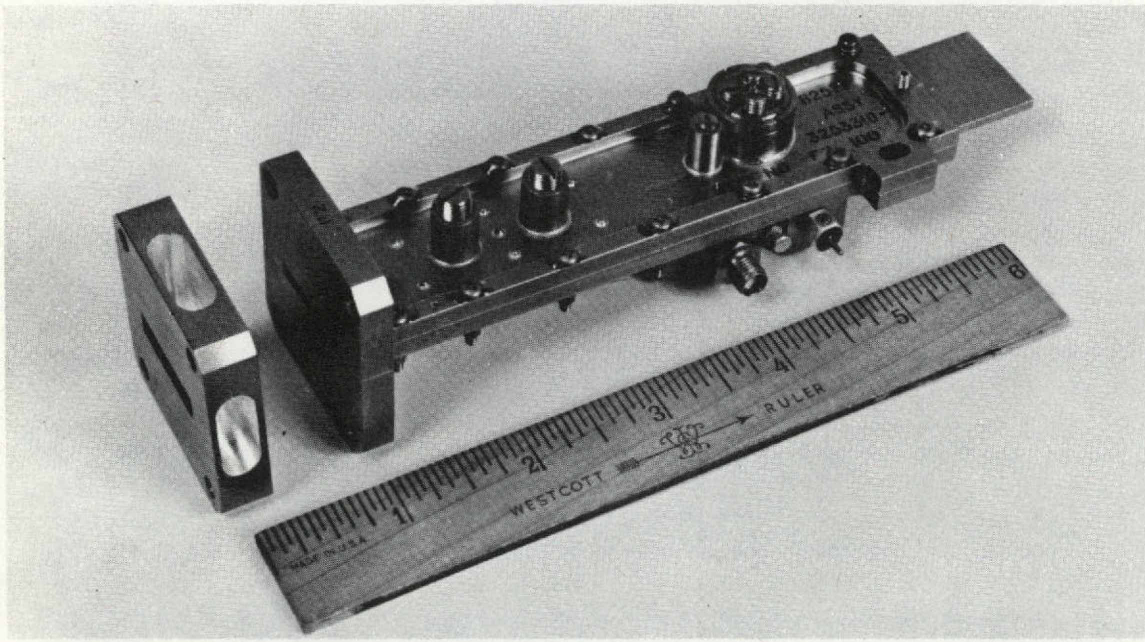


FIGURE 3-19. X5 FREQUENCY MULTIPLIER, 2 GHz TO 10 GHz (PHOTO 30153-64)

Regulators

The millimeter wave experiment incorporates four virtually identical current limited regulators. One regulates the bus voltage to 25.7 volts for the entire RF multiplier except the master oscillators. Another regulates the bus voltage to 23.5 volts for the master oscillators. The other two are incorporated in the 20/30 GHz modulator/power amplifier, one regulating the bus voltage to 25.7 volts for the communication mode modules and the other regulating the bus voltage to 25.7 volts for the multitone mode modules. They perform the following functions:

1) Provide dc power to the particular set of modules in response to commands

2) Provide current overload protection

3) Sustain overvoltage conditions and thus protect the modules from excessive voltages

4) Provide ±1 percent voltage regulation and ripple reduction.

The two regulators in the RF multiplier are dual units, as is the multitone regulator in the modulator/power amplifier, i.e., two regulators (one for each set of redundant modules) contained in a single housing. The communications regulator has only one regulator circuit, although it is packaged in the same chassis as the dual modules. All four regulators incorporate discrete components with soldered interconnections foamed in place inside their respective milled out chassis. One of the dual regulators is shown in Figure 3-20.

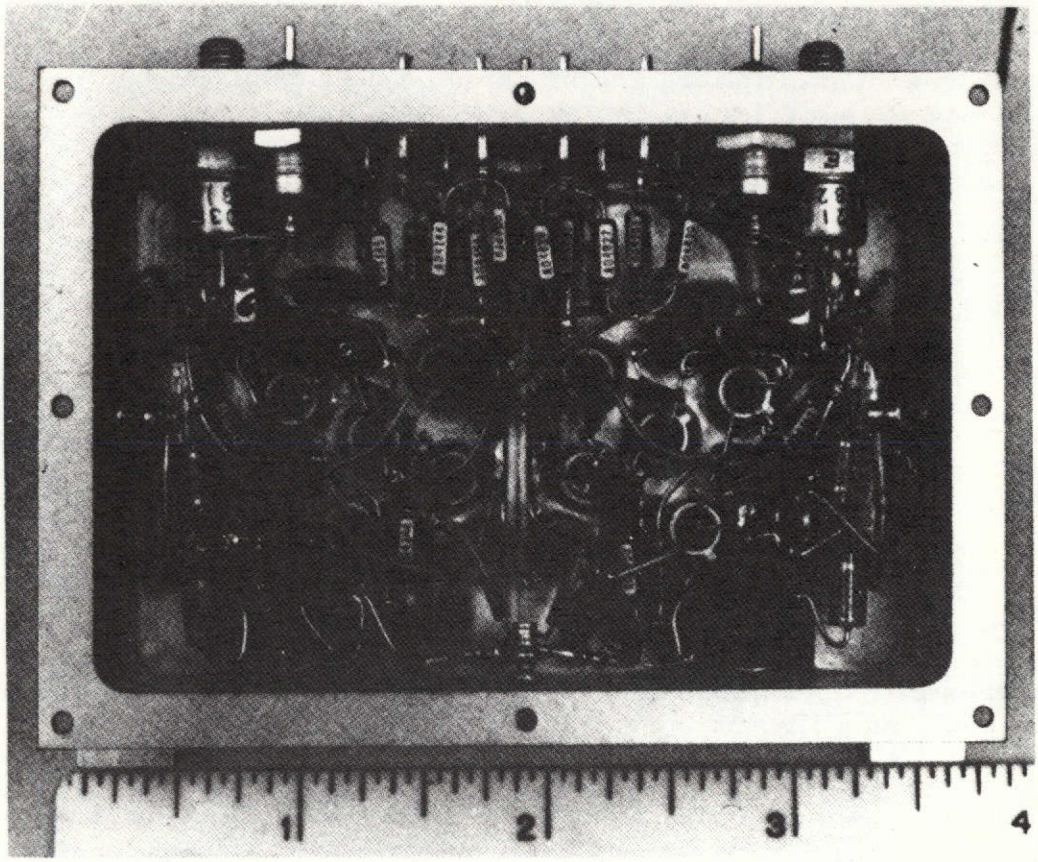


FIGURE 3-20. DUAL REGULATOR CHASSIS (PHOTO 30153-65)

20/30 GHz MODULATOR/POWER AMPLIFIER

The 20/30 GHz modulator/power amplifier unit provides the modulation of the RF signals, performs the final frequency multiplication to 20 GHz and 30 GHz, and provides final power amplification of the 20 GHz and 30 GHz to approximately 2 watts of output power. A block diagram of the unit is shown in Figure 3-21. As can be seen on the diagram, all elements except those associated with the communications mode, are fully redundant. Subsequent paragraphs of this subsection will describe the significant modules which make up the unit.

A photograph of the completed flight/prototype model of the unit is shown in Figure 3-22. The baseplate dimensions of the unit are 21.1 inches by 22.3 inches, but the overall dimensions, including waveguide protrusions, are 22.0 inches by 22.8 inches and its maximum height is 9.0 inches. The unit weighs 62.4 pounds. The primary structural member is a 0.2 inch thick magnesium plate, milled to a very fine surface flatness for good thermal interfacing to the spacecraft coldwall. The high heat dissipating components (TWTs and TWT power supplies) are mounted directly to this primary structural deck as shown in the photograph of the partially disassembled unit (Figure 3-23). Other modules are mounted on decks above these components.

For example, as shown at the right of Figure 3-23, the modulation modules and final frequency multipliers are mounted on the modulator deck, which is attached above the four TWTs. More detail on the configuration of the 20/30 GHz modulator/power amplifier may be found on its Interface Control Drawing (Reference 3-3).

The 20/30 GHz modulator/amplifier unit contains all of the interface connectors to the spacecraft including four Cannon D connectors for power, command, and the two sets of telemetry output signals and the coaxial connectors for either IF or baseband cross-strap of communications data. Pin connections on these connectors are given in Section 2 of this report. More detail on electrical signal routing within the unit may be found in the experiment interconnection diagram (Reference 3-2). When the experiment is fully turned on and with a 28 volt dc input power bus, the unit dissipates between 47.5 and 50.2 watts depending on the operating mode.

Multitone Amplifiers

The modulator/power amplifier contains four multitone amplifier modules, one redundant pair associated with providing modulation at 20 GHz and the other pair associated with 30 GHz. Each performs the same basic function, i.e., amplification of the 10 dBm, 180 MHz signal from the RF multiplier to the proper level for driving the phase modulators. Although they are all nearly the same, there are two differences. First, the modules associated with the 20 GHz branch contain a power divider so that the 180 MHz input signal power may be split, half of it driving the amplifier itself and half fed out to the amplifier associated with the 30 GHz branch. The other difference is that the output level of each amplifier is adjusted to optimize the multitone modulation for the particular combination of system elements. The adjustment results in a distribution in output power from the various amplifiers from 18.2 to 21.2 dBm. The typical swept frequency output response of the multitone amplifier is shown in Figure 3-24. Each amplifier incorporates discrete components with soldered interconnections foamed in place inside its wrap around chassis.

Phase Modulators

Modulation of the RF signal for the multitone mode of operation occurs in the phase modulators. This modulation occurs at 10 GHz, using the 10 GHz signal from the RF multiplier, and the modulating signal is the 180 MHz signal from the multitone amplifiers. A redundant pair of phase modulators is dedicated to the 20 GHz branch and a pair is dedicated to 30 GHz. Modulation in the former has a higher index than in the latter so that, after final multiplication by two or by three, the final modulation indices are the same, and the same nine spectral line pattern exists around the 20 GHz center frequency as exists around 30 GHz.

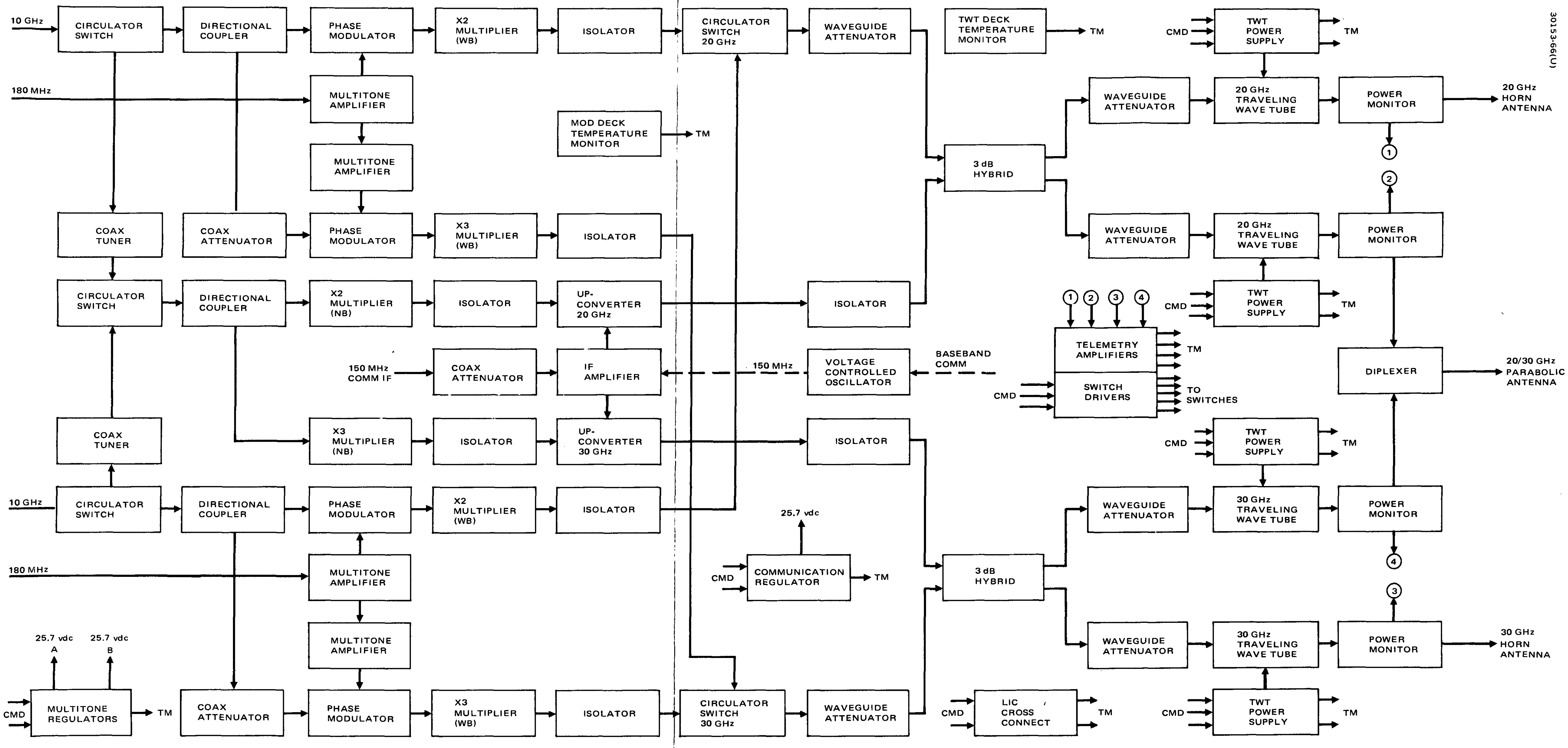


FIGURE 3-21. 20/30 GHz MODULATOR/POWER AMPLIFIER BLOCK DIAGRAM

FOLDOUT FRAME 1

FOLDOUT FRAME 2

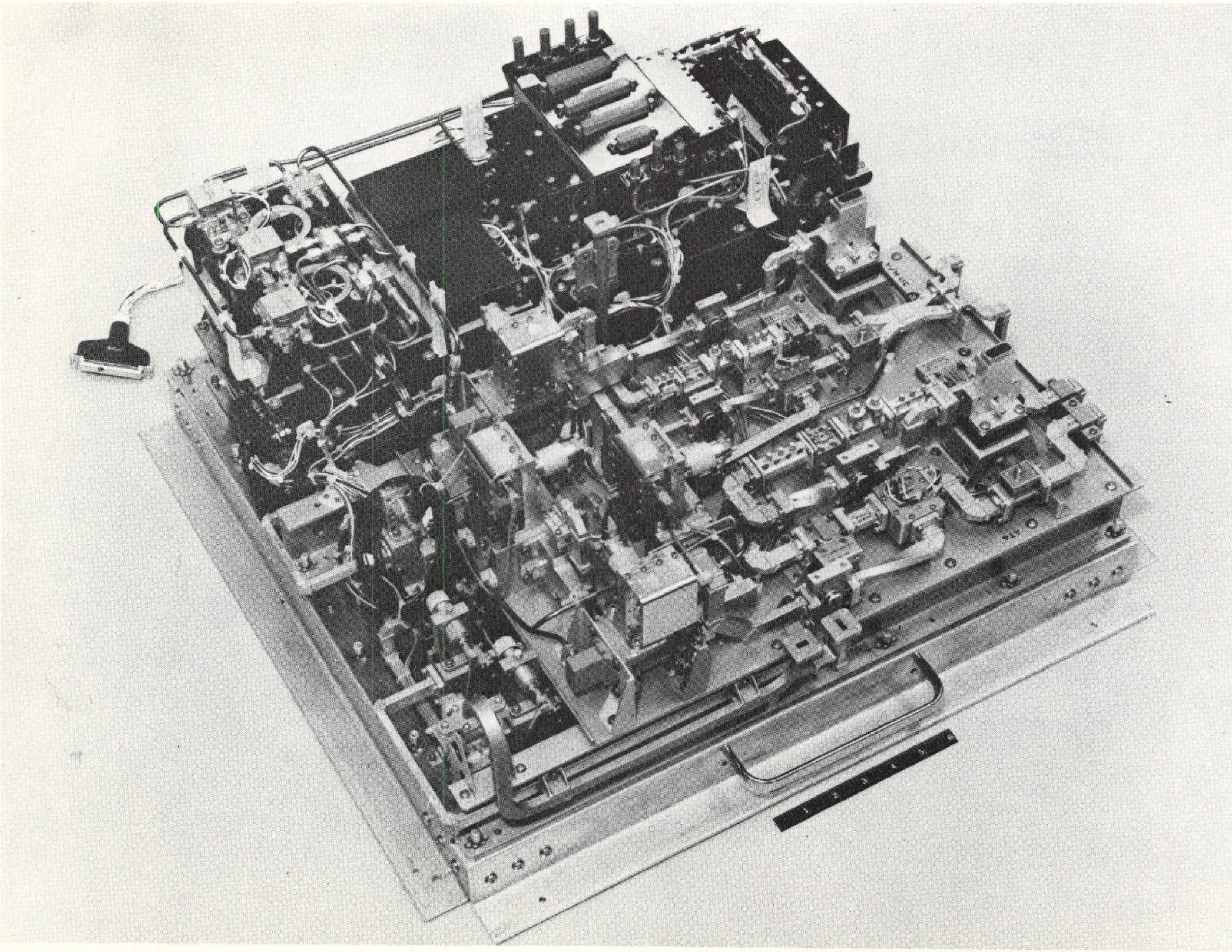


FIGURE 3-22. FLIGHT/PROTOTYPE MODEL 20/30 GHz MODULATOR/POWER AMPLIFIER UNIT (PHOTO 4R26858)

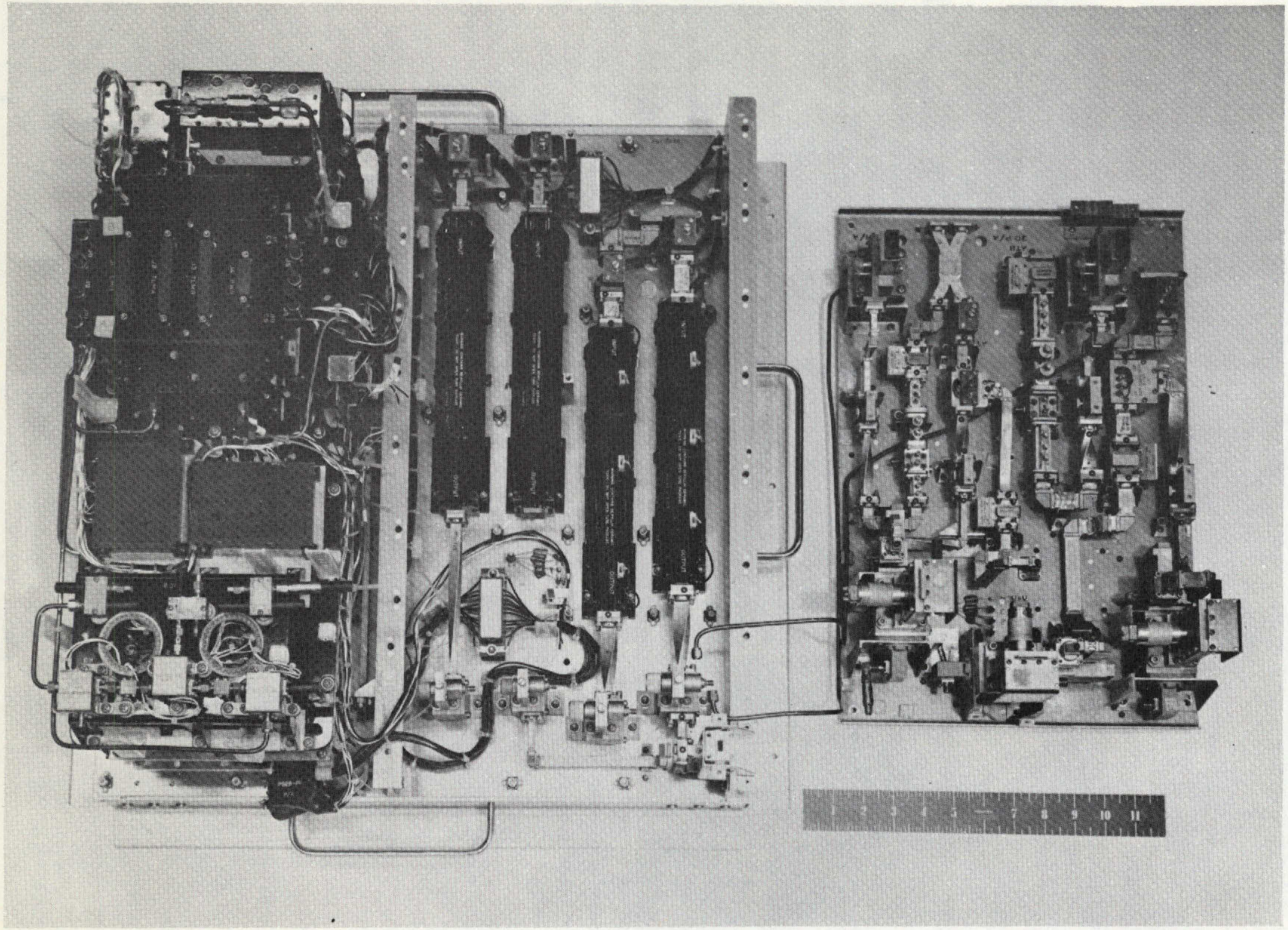


FIGURE 3-23. 20/30 GHz MODULATOR/POWER AMPLIFIER PARTIALLY DISASSEMBLED (PHOTO 72-13617)

C2

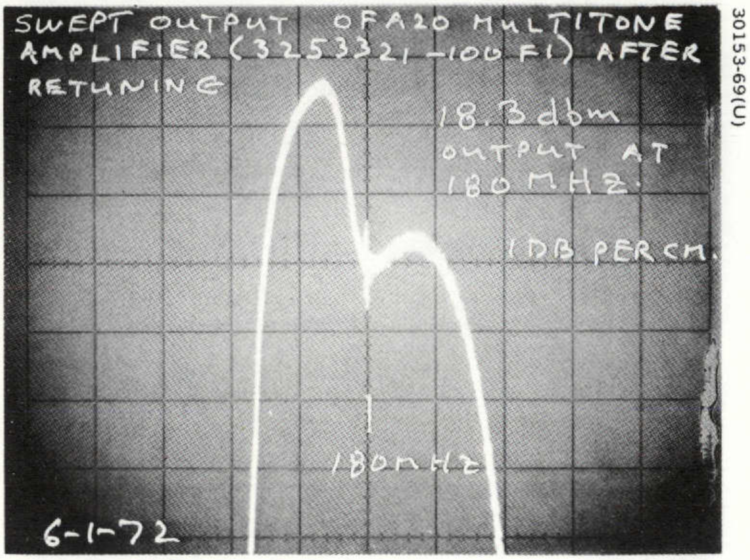


FIGURE 3-24. MULTITONE AMPLIFIER SWEPT FREQUENCY RESPONSE

Each phase modulator consists of a 10 GHz waveguide circulator, a shorted waveguide section with a varactor diode positioned across it, and a VHF circuit. Schematically the phase modulator may be represented as shown in Figure 3-25. As can be seen in the diagram, the 10 GHz signal is directed into the section of shorted waveguide by the circulator. The varactor diode, along with the tuning elements in the waveguide, presents a susceptance to the 10 GHz signal which varies with the voltage applied to the diode. The reflected 10 GHz, which is directed through the output port of the circulator, will be shifted in phase depending on the value of susceptance. When the 180 MHz VHF signal is applied across the varactor diode, the effect is a phase modulation on the 10 GHz output at a 180 MHz rate.

The VHF circuit portion of the phase modulator provides matching of the module to the 50 ohm line coming from the multitone amplifier by means of a matching network. Also included is a low pass filter which allows the 180 MHz signal to reach the varactor diode but prevents 10 GHz power from being fed back into the VHF circuits. Diode bias is also provided from the VHF portion of the module.

Preliminary adjustments were made in the phase modulators to achieve on the order of ±90 degree phase shift, to achieve a total insertion loss of approximately 2. 5 dB, and to minimize the variation of insertion loss as a function of phase angle. The variation of insertion loss as a function of phase angle results in amplitude modulation of the signal which is undesirable since AM to PM conversion effects in the saturated TWT can result in perturbations to the desired spectrum. Figure 3-26 shows an example of the phase shift achieved by the phase modulators together with the small amount of associated insertion loss variation. The figure is a photograph of the polar display on a network analyzer. Final adjustments were made on the phase modulators at the system level to achieve optimum multitone spectrums for each combination of phase modulator, final multiplier, and TWTA.

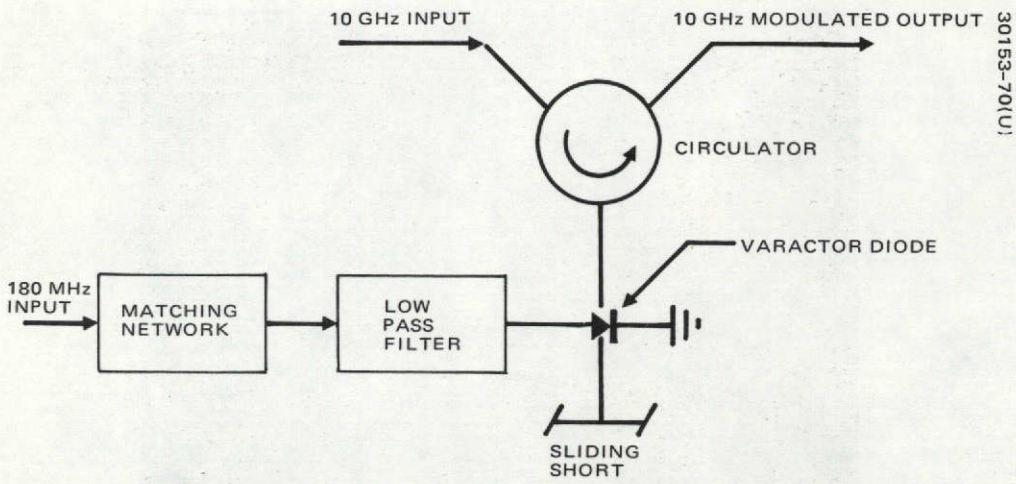


FIGURE 3-25. PHASE MODULATOR SCHEMATIC DIAGRAM

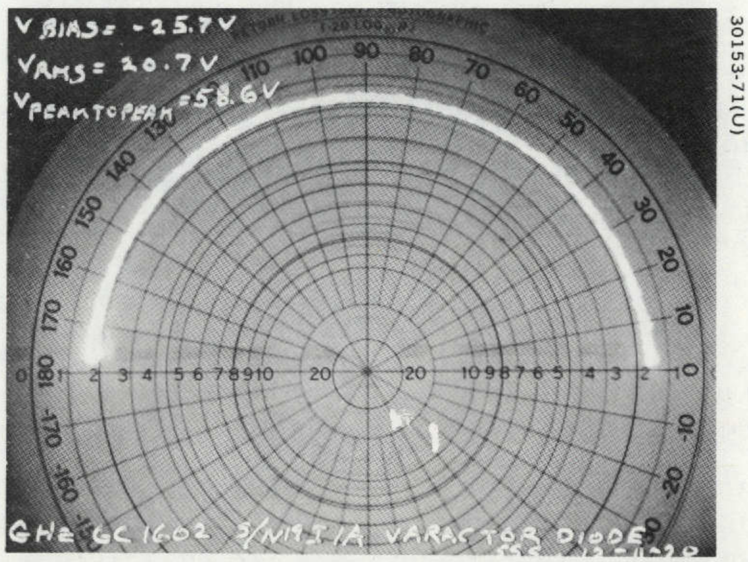


FIGURE 3-26. NETWORK ANALYZER DISPLAY
OF PHASE SHIFT IN PHASE MODULATOR

A photograph of the phase modulator associated with the 30 GHz branch is shown in Figure 3-27. Also shown in Figure 3-27 is the complete 30 GHz phase modulator group, each containing a 10 GHz coax to waveguide transition connected to a circulator input, a wideband X3 multiplier connected to the circulator output port, and a 30 GHz isolator at the output of a short waveguide run.

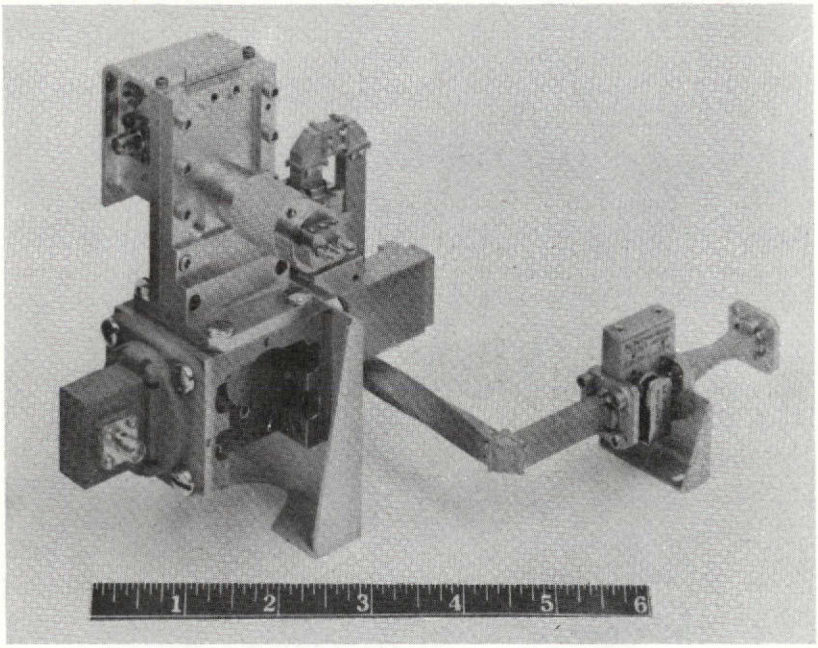


FIGURE 3-27. 30 GHz PHASE MODULATOR
(PHOTO 71-10080)

Final Multipliers

The 20/30 GHz modulator/power amplifier contains six final frequency multipliers, two wideband X2 multipliers, one narrowband X2 multiplier, two wideband X3 multipliers, and one narrowband X3 multiplier. The construction of X2 and X3 multipliers is quite similar, and there is no difference between the narrowband and wideband versions except for the tuning. (Wideband modules were optimized for bandwidth at the expense of insertion loss, whereas narrowband modules were optimized for insertion loss.) Photographs of a X2 multiplier and a X3 multiplier are shown in Figures 3-28 and 3-29.

The multipliers consist of an X band (WR 90) waveguide, perpendicular in the H plane to a K band waveguide (K_u band or WR 42 for the X2 multiplier and K_a band or WR 28 for the X3 multiplier). Both waveguides are offset in the E plane and share a common broad wall. The 10 GHz input signal excites a varactor diode in the large waveguide. The diode generates higher harmonics which are coupled through the common broad wall by a dipole that extends from the diode holder in the large waveguide to inside the small waveguide. Tuning is accomplished with a sliding short and capacitive tuning screws in both waveguides. Figure 3-30 shows the swept frequency output response of one of the wideband doublers, and Figure 3-31 shows the response of one of the wideband triplers. Insertion loss for the wideband doublers was approximately 13 dB and for the wideband triplers approximately 7 dB.

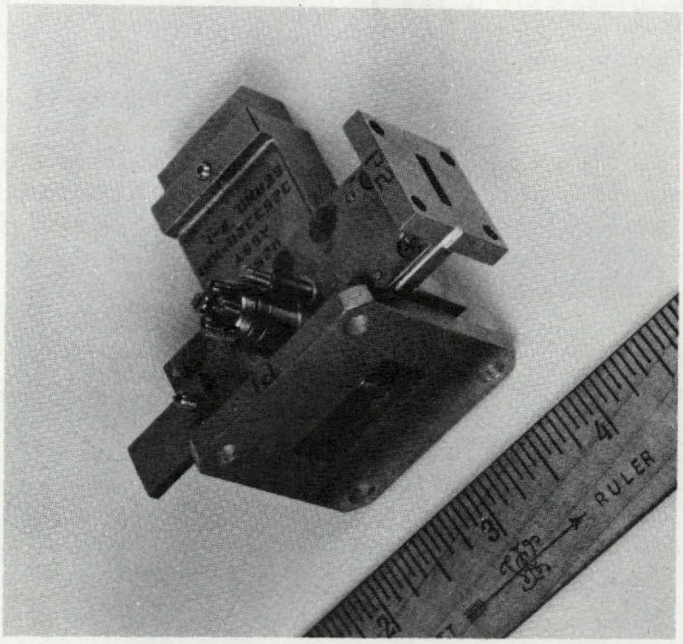


FIGURE 3-28. X2 FREQUENCY MULTIPLIER
(PHOTO 30153-73)

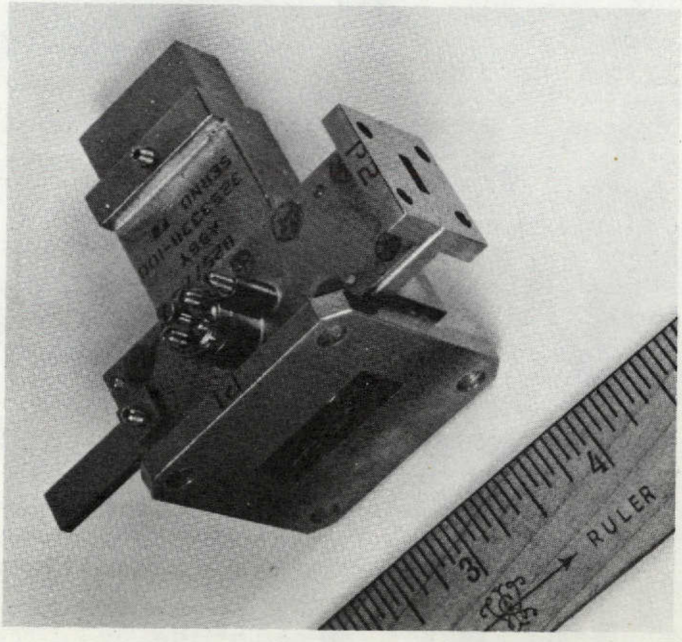


FIGURE 3-29. X3 FREQUENCY MULTIPLIER
(PHOTO 30153-74)

30153-75(U)

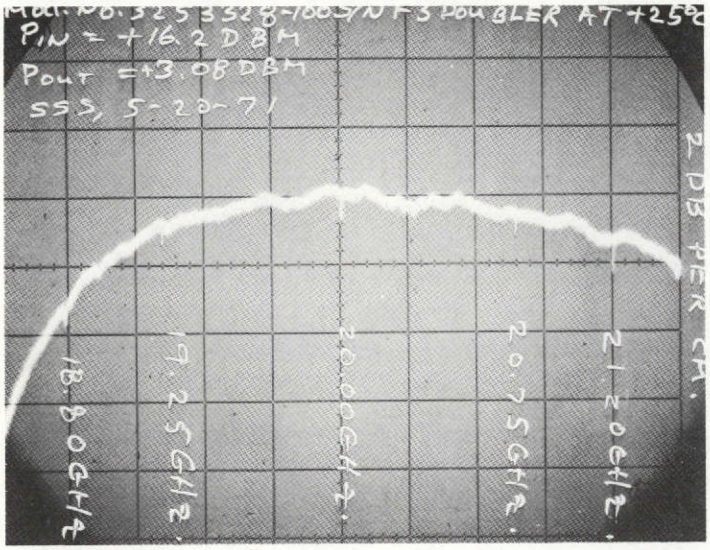


FIGURE 3-30. X2 MULTIPLIER (WIDEBAND) SWEPT FREQUENCY RESPONSE

30153-76(U)

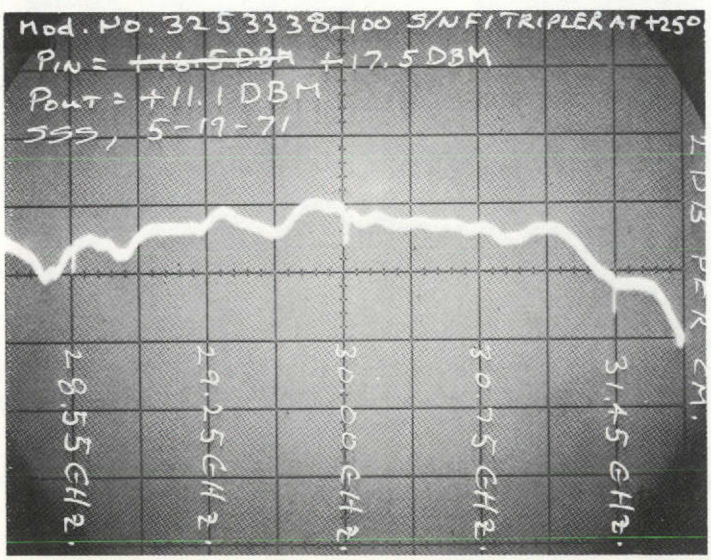


FIGURE 3-31. X3 MULTIPLIER (WIDEBAND) SWEPT FREQUENCY RESPONSE

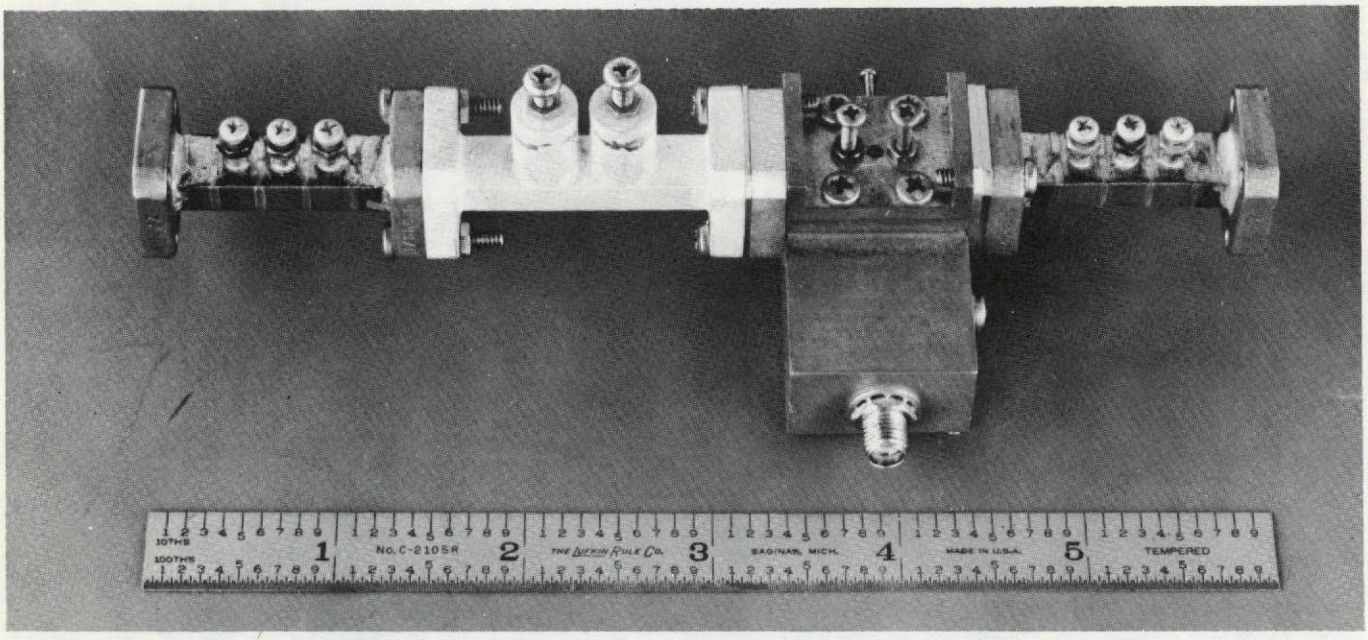


FIGURE 3-32. 30 GHz UPCONVERTER BREADBOARD MODEL (PHOTO 4R16826)

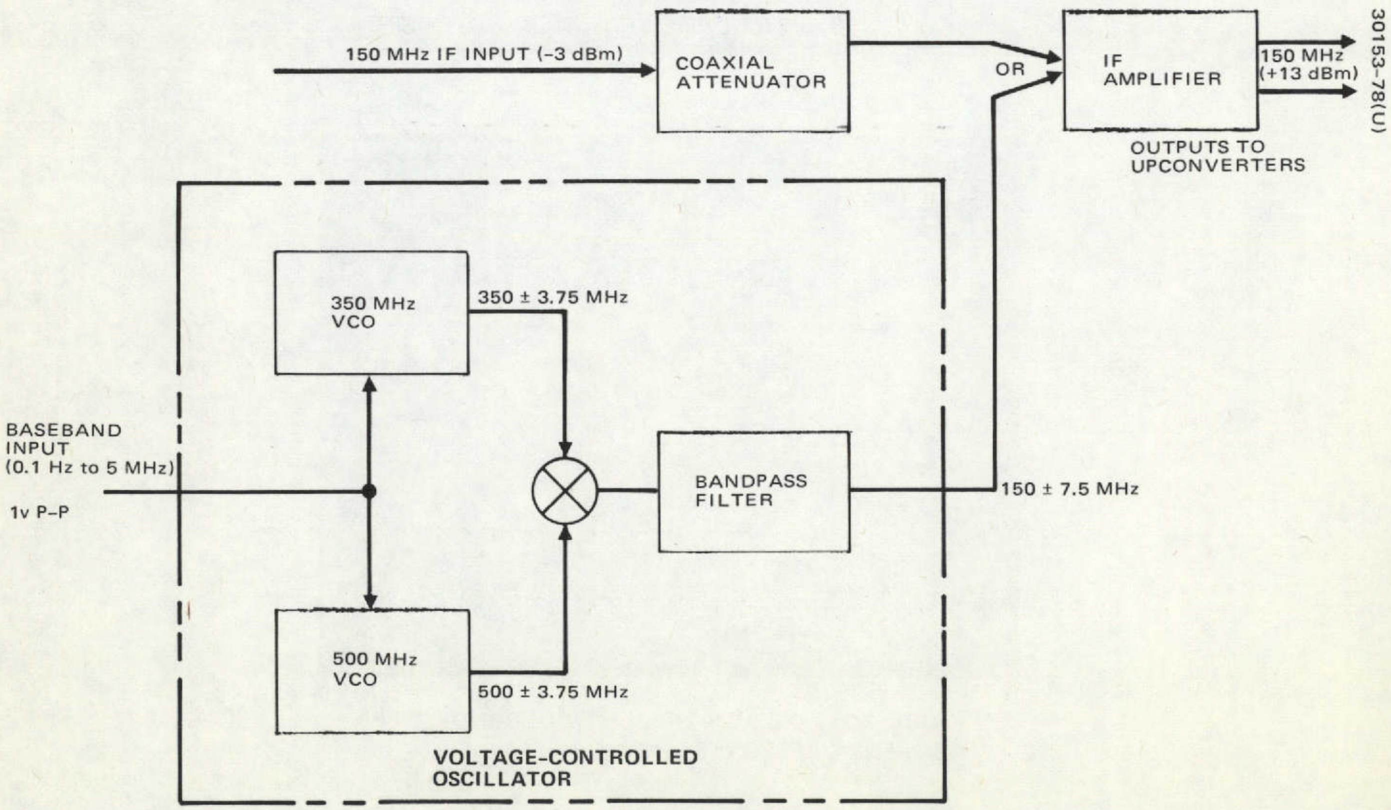


FIGURE 3-33. COMMUNICATIONS PROCESSOR GROUP BLOCK DIAGRAM

Upconverters

Two upconverters are included in the modulator/power amplifier, one at 20 GHz and one at 30 GHz. Their functions are to convert the 150 MHz frequency modulated IF transponder into signals at 20.15 GHz and 30.15 GHz signals for retransmission to earth. Required channel bandwidth is 40 MHz.

The basic design of the two upconverters is the same with dimensional scaling and filter changes to accomplish the same function at the two frequencies. A photograph of the breadboard 30 GHz upconverter is shown in Figure 3-32. It consists of an input bandpass filter at 30 GHz, impedance matching, and low pass filter networks for the 150 MHz signal port, the varactor diode mixer section, and two stages of output bandpass filtering to suppress sidebands other than the desired 30.15 GHz output.

Each of the two upconverters was optimized to yield -3.5 dBm at the output with a 150 MHz signal level of +13 dBm. The conversion loss from pump power to output signal power was 12 dB for the 20 GHz module and 15 dB for the 30 GHz.

Communications Processor

The communications processor group consists of two modules: the IF amplifier and the voltage controlled oscillator (VCO). A block diagram of this group is shown in Figure 3-33. Two alternative connections have been provided for, and the choice between these will be made during spacecraft level tests. The first, and most desirable, alternate configuration is to use the 150 MHz IF directly from the spacecraft transponder. Since this signal has a level of -3 dBm, it first passes through an attenuator and then is amplified by the 40 dB gain IF amplifier. In the second, less desirable, alternative, the baseband communications signal is received from the demodulator of the spacecraft transponder at a 1 volt peak-to-peak level. This baseband signal controls the frequency in the VCO, and the result is a frequency modulated 150 MHz signal which is applied directly to the IF amplifier with no attenuation. In either alternative the output level of the 150 MHz signal from the IF amplifier is +13 dBm.

The IF amplifier has two stages of transistor amplification. It incorporates discrete components with soldered interconnections foamed in place inside its wrap around chassis. The amplifier is shown in Figure 3-34 prior to being foamed.

The 150 MHz VCO consists of two VCOs, one at 350 MHz and the other at 500 MHz, the outputs of which are mixed to provide the output at 150 MHz. The technique of using two VCOs results in an oscillator which has an extremely linear frequency versus control voltage characteristic. The superior linearity results because the percentage frequency change required from each of the two oscillators is small compared to the resulting percentage frequency change at the output frequency. The oscillator has a linearity of about one percent of the peak deviation over a frequency deviation range of ±7.5 MHz. (Bandwidth of TV transmission using Carson's rule is $BW = 2\ (fm+\Delta f) = 2\ (5.0+7.5) = 25$ MHz.)

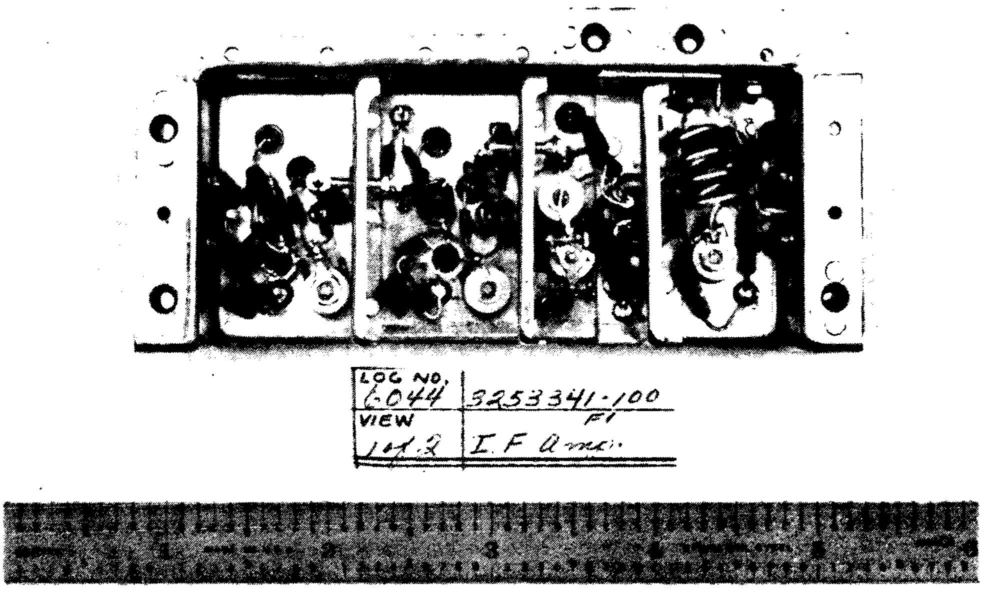


FIGURE 3-34. IF AMPLIFIER (PHOTO 30153-79)

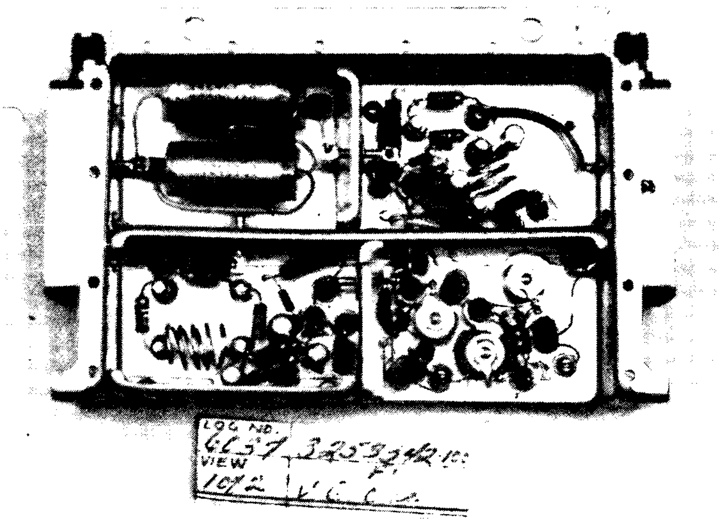


FIGURE 3-35. VOLTAGE CONTROLLED OSCILLATOR
(PHOTO 30153-80)

The VCO incorporates discrete components with soldered interconnections foamed in place inside its chassis. It is shown in Figure 3-35 prior to being foamed.

Circulator Switches

Five circulator switches are contained in the modulator/power amplifier, three 10 GHz switches incorporating coaxial connections, one 20 GHz waveguide circulator switch, and one 30 GHz waveguide circulator switch. Direction of the RF energy flow is controlled by the direction of the magnetic field applied across the ferrite at the junction. The magnetic field is produced by a magnet which is polarized by an electric current pulse in one direction through the coil. Because of the square loop properties of the magnet, it will remain polarized in this direction until a current pulse in the opposite direction is applied to the coil. The switches are therefore latching devices. Current pulses are supplied to the switches in response to commands by the switch driver circuits contained in the switch driver/telemetry amplifier module.

Traveling-Wave Tubes

Two different traveling-wave tubes were developed for use in the modulator/power amplifier. Two each were used and the Hughes designations are 268H for the TWT operating at 20 GHz, and 254H for the 30 GHz TWT. Each was required to produce a minimum of 2 watts of RF output power at saturation and have a minimum of 42 dB of gain at saturation with a bandwidth of at least 1450 MHz.

The designs of the two TWTs are quite similar with differences to attain the desired performance at the two frequencies. Each contains an electron gun using a barium oxide coated cathode with very modest cathode current loading to provide long life. The beams are converged to the very small beam sizes by similar electrode configurations and focusing is provided in each case by a periodic permanent magnet stack made of platinum-cobalt magnets. RF energy is coupled in through a waveguide matching structure, a waveguide to coaxial transition, and transfer to the helix through a coaxial match pipe which includes a ceramic RF window into the vacuum envelope. After amplification by interaction between the electron beam and RF propagating along the helix slow wave structure, the RF exits from the TWT in the same way it entered, but in reverse. Each TWT operates with a depressed collector for maximum total TWT efficiency.

Significant design and operating parameters in a typical 268H TWT and a typical 254H TWT are given in Table 3-2. The variation of RF output power as a function of frequency across the band is shown in Figure 3-36 for a typical 268H TWT and in Figure 3-37 for a typical 254H TWT. A photograph of a flight/prototype model of the 268H TWT connected to its associated power supply is shown in Figure 3-38, and a similar photograph of the 254H is shown in Figure 3-39.

TABLE 3-2. TWT DESIGN AND OPERATING PARAMETERS

Parameter	Typical 268H	Typical 254H
Cathode loading, amperes/cm^2	0.200	0.200
Convergence factor	50:1	37:1
Diameter of beam, inches	0.010	0.013
Diameter of helix wire, inches	0.006	0.005
Helix length, inches	5.04	5.57
Perveance, μperv	0.058	0.027
Axial field intensity, gauss	2500	2200
Voltages + Currents		
E_f, volts	3.8	3.8
I_f, amperes	0.25	0.25
E_b, volts	-3000	-4000
I_b, ma	13.0	11.5
E_k, volts	-3800	-5500
I_w, ma	0.4	0.4
E_a, volts	200	200
I_a, ma	<0.01	<0.01
Total tube efficiency, percent	23.6	12.6
Power out, watts	3	2.5
Gain, dB	45	42
Dimensions		
Length, inches	9.6	10.5
Width, inches	1.75	1.75
Height, inches	2.00	2.00
Weight, pounds	1.38	1.44

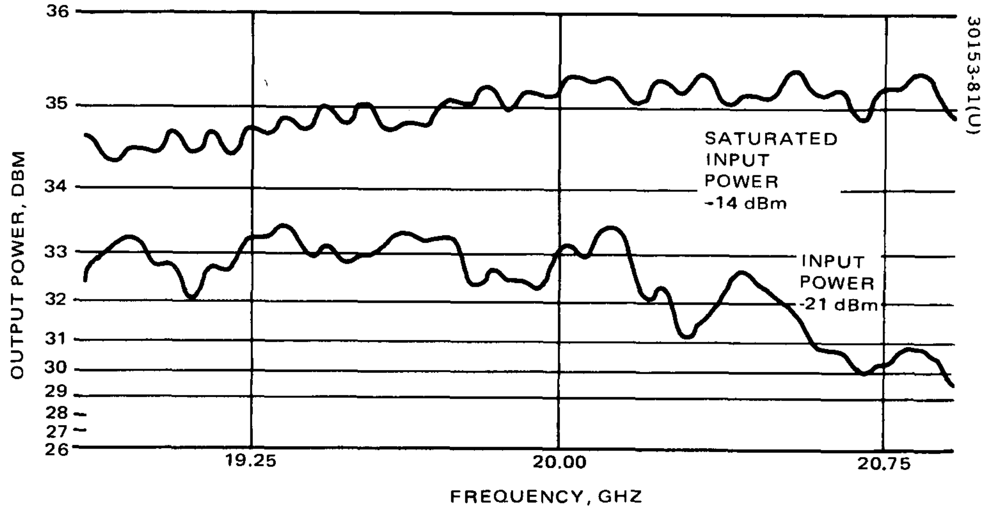


FIGURE 3-36. RF OUTPUT POWER FOR TYPICAL 268H TWT (SERIAL NO. F-1)

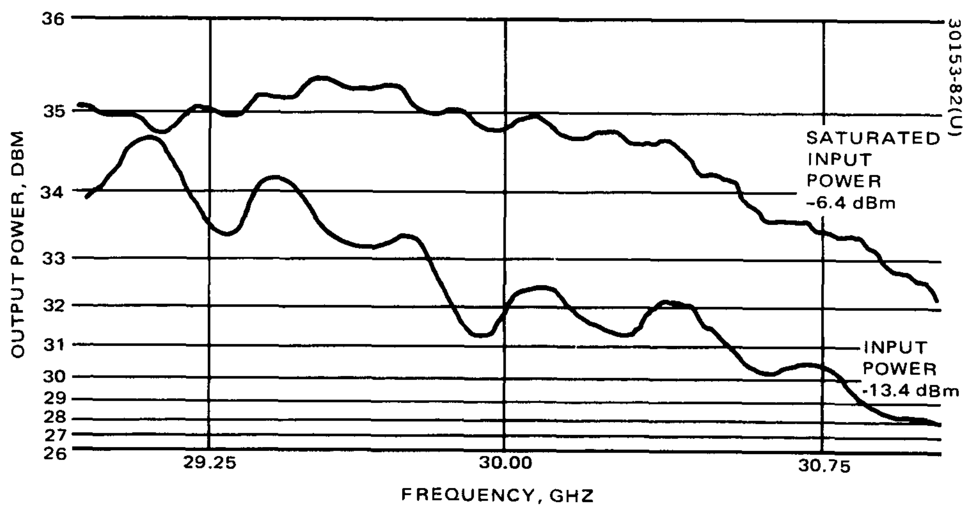


FIGURE 3-37. RF OUTPUT POWER FOR TYPICAL 254H TWT (SERIAL NO. F-1)

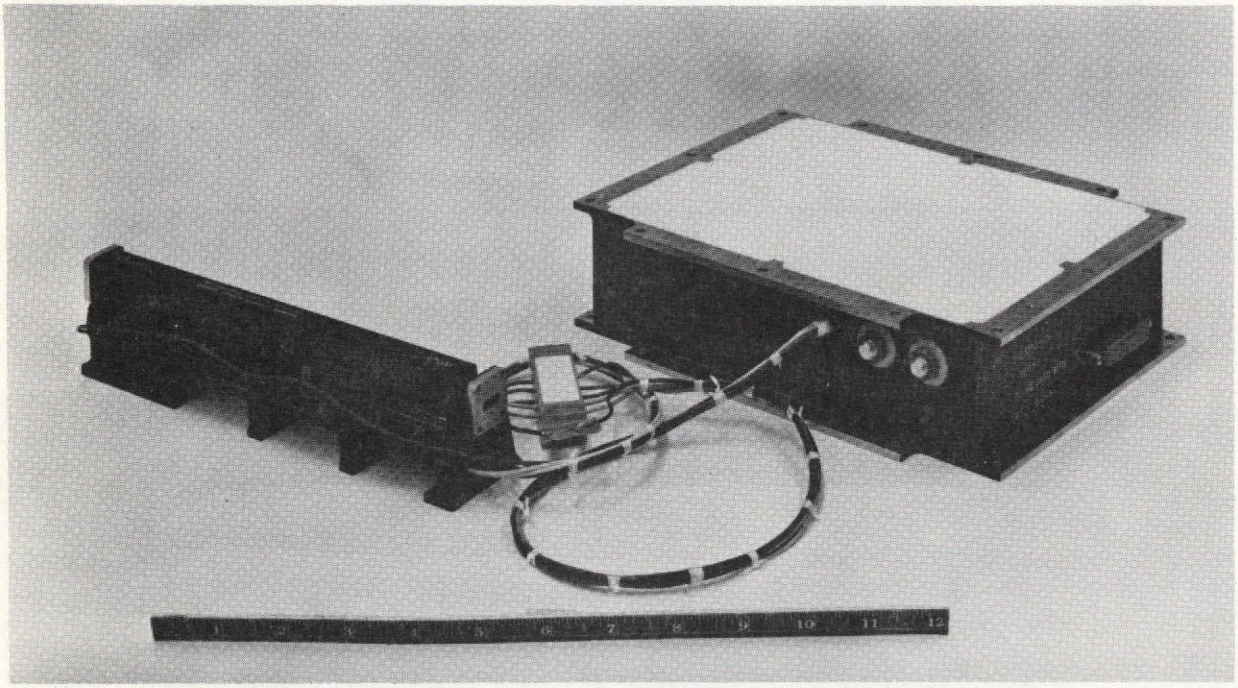


FIGURE 3-38. 20 GHz TRAVELING–WAVE TUBE AMPLIFIER (PHOTO 4R25309)

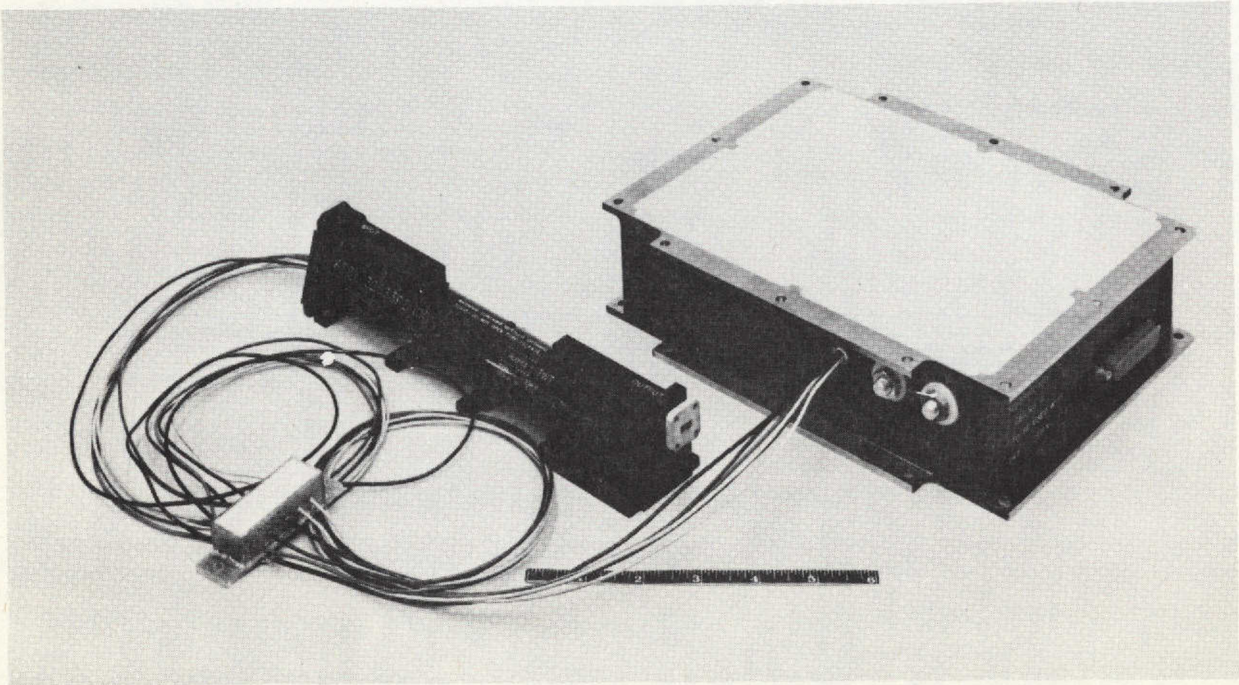


FIGURE 3-39. 30 GHZ TRAVELING-WAVE TUBE AMPLIFIER (PHOTO 4R25523)

Traveling-Wave Tube Power Supplies

The power supplies for the 20 and 30 GHz traveling-wave tubes are similar. Each power supply weighs 6.6 pounds and consists of a series dissipative type regulator, a filament supply, and a high voltage converter. A block diagram for the 20 GHz TWT power supply is shown in Figure 3-40. The 30 GHz TWT power supply is of the same basic design as the 20 GHz supply except for the use of a voltage tripler instead of a doubler to provide the higher voltage required. Table 3-3 gives the required voltages for the power supplies.

A filament ON command turns on the +24 volt series dissipative regulator. This applies power to the filament inverter which is a self-starting saturable core square wave power oscillator, supplying a 3.8 volts rms, 4.5 kHz square wave to the TWT filament. The high voltage converter is turned on by means of a high voltage ON command which starts the drive inverter. The drive inverter, a saturable core square wave oscillator, supplies drive to the high voltage converter, which in turn provides the anode, cathode, and collector dc voltages. Application of an OFF command turns off the input series regulator, removing high voltage and filament power.

Three automatic safety features are incorporated into the power supplies. First, there is a helix current sensing circuit which causes the complete power supply to turn off if the steady state helix current exceeds the trip level. A time constant is built into the circuit so that the normal helix current surge during turnon will not turn off the supply. A second feature is that if the steady state voltage out of the input series regulator drops below approximately 22 volts dc for any reason (such as a down stream short circuit), the complete power supply will turn off. Finally, if the input voltage from the load interface circuit to the experiment decreases below about 23.5 volts dc, the complete power supply will turn off. Restoration of the power supply to operation must be done by the normal ON commands (although this can only be done if the fault has cleared).

TABLE 3-3. 20 AND 30 GHz TRAVELING WAVE TUBE POWER SUPPLY REQUIREMENTS

Requirement	20 GHz	30 GHz
Filament voltage, E_f, volts	3.8 to 4.0	3.8 to 4.0
Anode voltage, E_a, volts	+25 to +500	+25 to +500
Collector voltage, E_b, volts	-2500 to -3000	-3400 to -4000
Cathode voltage, E_k, volts	-3650 to -3950	-5400 to -6000
$E_k - E_b$, volts	950 to 1150	1400 to 2000
Helix current, I_h, ma	0.1 to 1.0	0.1 to 0.5
Cathode current, I_k, ma	12 to 14	10.5 to 12.5
Total input power, watts	17 maximum	24 maximum

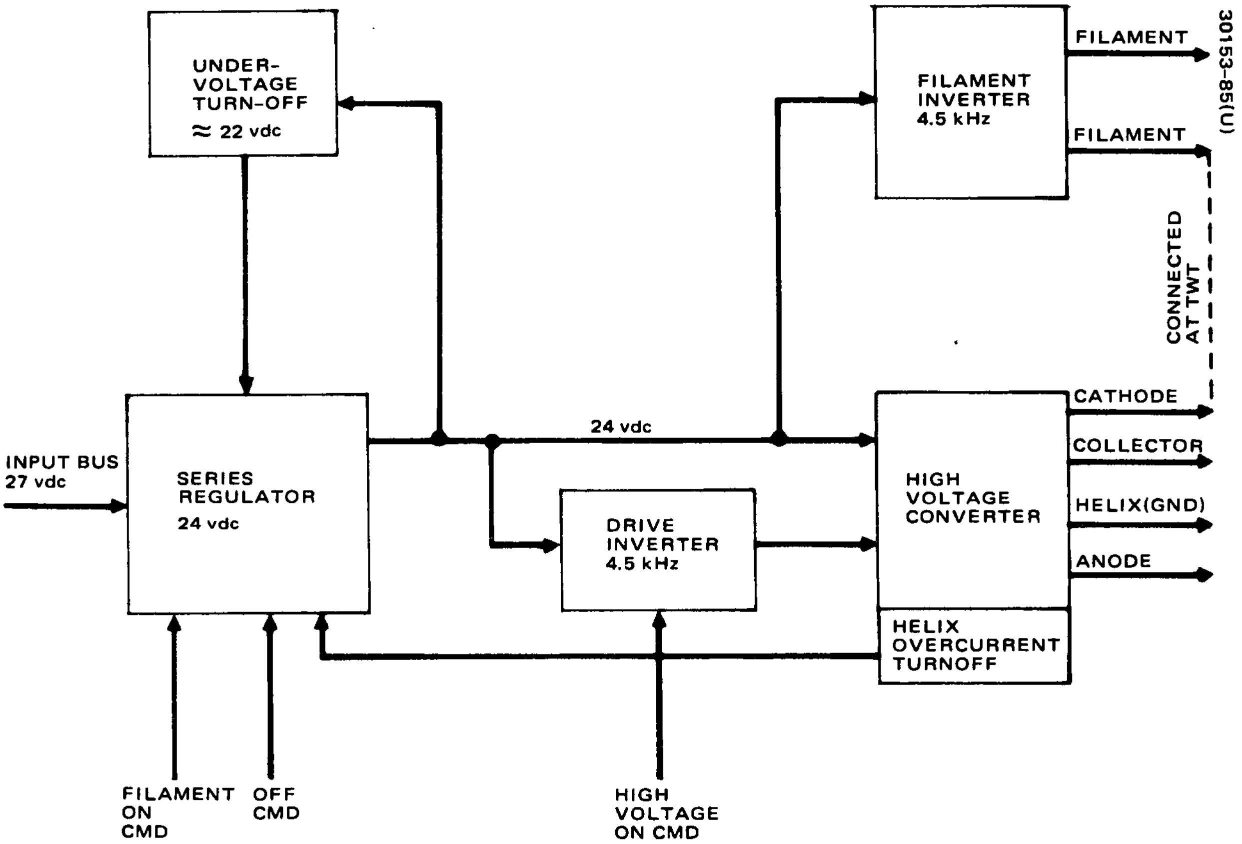


FIGURE 3-40. TWT POWER SUPPLY BLOCK DIAGRAM

All of the circuitry up to and including the inverters incorporates discrete components with soldered interconnections foamed in place within the machined magnesium housing. All of the high voltage components, including the output transformer of the filament inverter, are encapsulated in aluminum oxide loaded solithane. This solid encapsulated high voltage module is bonded to the magnesium housing and a layer of foam is formed around it to provide additional structural support. The 20 and 30 GHz power supplies in their final flight configuration may be seen in the photographs of Figures 3-38 and 3-39.

RF Power Monitors

The 20 and 30 GHz RF power monitors are similar in design. The 30 GHz RF power monitor is shown in Figure 3-41. Each power monitor consists of a waveguide directional coupler, a diode detector housed in the secondary waveguide, and a dc amplifier. The RF energy from the TWT output is coupled through a 30 dB Moreno crossguide coupler to a waveguide mounted diode detector. The diode is a silicon point contact device designed especially for power monitor applications. High reliability is achieved by maintaining the power levels on the diode equal to or less than one half of its maximum rating. The diode is loaded with a low impedance which results in small voltage variations over temperature. The diode output voltage is amplified by an integrated circuit dc amplifier with a gain of 20. The integrated circuit, which is contained in the switch driver/telemetry amplifier module, is a microampere 741 operational amplifier. Temperature compensation of the bias circuitry limits the gain variation over the temperature range and to some degree compensates for the temperature variation of the diode. Performance data on the RF power monitors is given in Section 2 of this report.

Diplexer

The diplexer enables the parabolic antenna to be driven by the Serial No. F-1, 20 GHz TWT and by the Serial No. F-2, 30 GHz TWT, one at a time or both together. The diplexer, shown in Figure 3-42, has two input ports. The 20 GHz input port is connected to a section of WR 42 waveguide from the 20 GHz power monitor and the 30 GHz input port is connected to a section of WR 28 waveguide from the 30 GHz power monitor. The WR 34 waveguide output port is connected to a section of WR 34 waveguide which is attached to the 20/30 GHz, WR 34 waveguide COMSAT filter and then to the parabolic antenna input port. The 20 GHz signals experience a 0.4 dB insertion loss through the diplexer and the 30 GHz signals experience a 0.3 dB insertion loss through the diplexer.

20/30 GHz HORN ANTENNAS

The rectangular horn antennas and the assembly plate, upon which they are both mounted, are made of an aluminum honeycomb sandwich construction. This construction results in a minimal overall weight for the

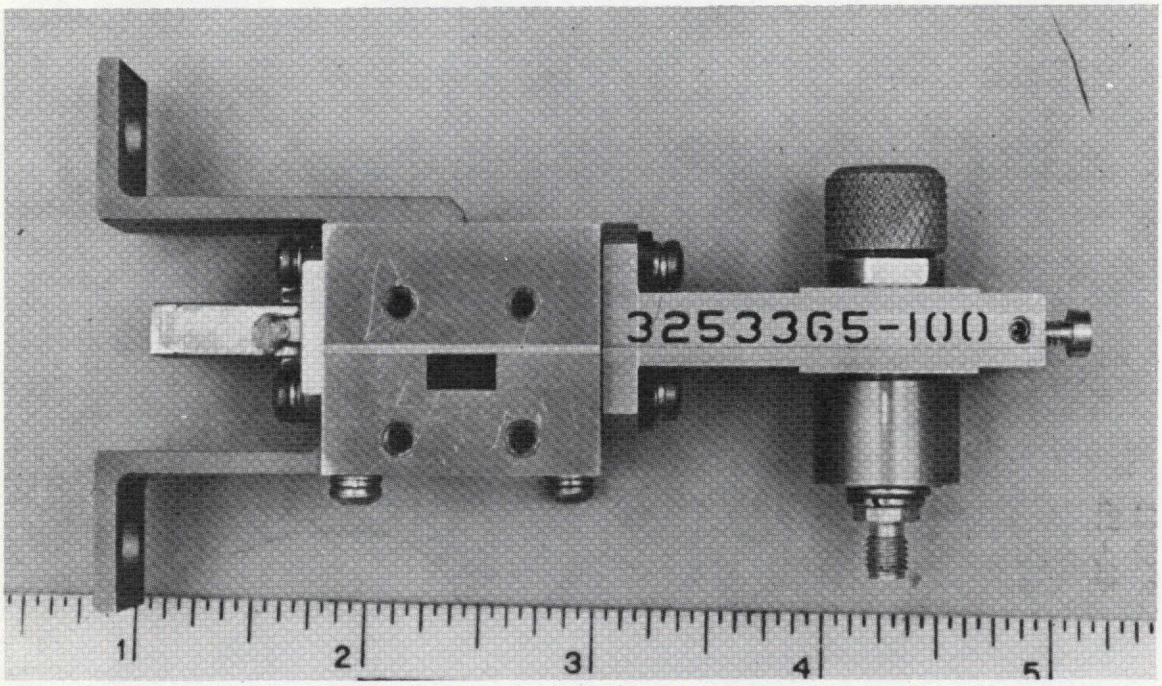


FIGURE 3-41. 30 GHz POWER MONITOR (PHOTO 30153-86)

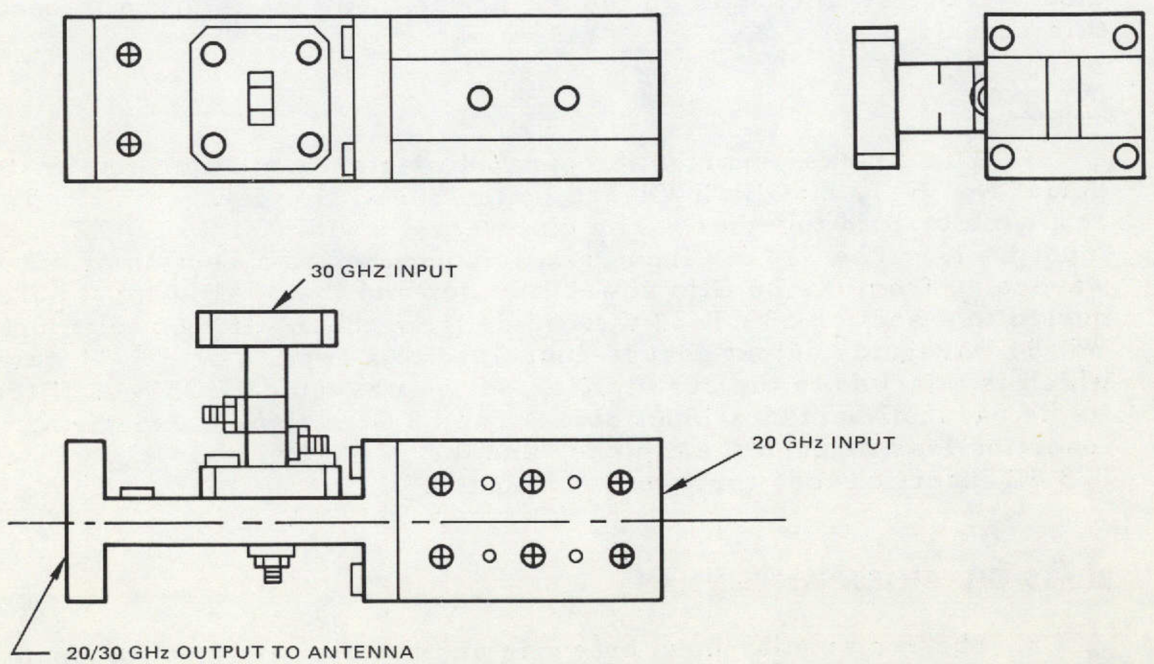


FIGURE 3-42. DIPLEXER

20/30 GHz horn antenna assembly of 4.31 pounds and provides adequate mechanical integrity together with flat, smooth, and electrically accurate surfaces inside the horns. The flared section of each horn is fabricated from 0.25 inch thick aluminum honeycomb sandwich plate. The honeycomb sandwich consists of 1/8 inch cells, 0.002 inch (minimum) thick aluminum cover sheet outside and 0.005 inch thick beryllium copper inside with 0.003 inch thick epoxy-glass preimpregnated as the bond between core and covers. Foaming tape is placed at the longitudinal corners to join the four separate core pieces. The inner cover sheets are joined together by soldering and are attached to a machined waveguide and flange section with conductive epoxy. The cells at the open end of the horns are filled with syntactic foam.

The mounting plate is of aluminum honeycomb sandwich construction, 3/8 inch thick. Prior to attaching the horns to the plate, they were collimated on the antenna test range so that their RF axis are parallel to each other and approximately parallel to the flange of the mounting plate. A calibration reading referenced to the permanently attached boresight mirror defines the true electrical axis. A photograph of the horn antenna assembly is shown in Figure 3-43 and more detail on the configuration may be found on the interface control drawing (Reference 3-4).

The 20 and 30 GHz horn antennas are linearly polarized with the E plane aligned in the N-S direction. The electrical performance of both horn antennas is presented in Table 3-4. The E and H plane radiation patterns of the 20 and 30 GHz horn antennas are presented in Figures 3-44 through 3-47.

TABLE 3-4. 20/30 GHz HORN ANTENNAS POSTENVIRONMENTAL PERFORMANCE

Frequency	VSWR (1.3:1 Maximum)	Gain (27 dB Minimum)	Patterns (3 dB Beamwidth) E Plane (5.5 Degree Minimum)	Patterns (3 dB Beamwidth) H Plane (7.8 Degree Minimum)	Electrical Offset, (0.3 Degree Maximum) E	Electrical Offset, (0.3 Degree Maximum) H
19.25	1.16	27.28	6.6	8.2	-0.05	-0.10
20.15	1.10	27.25	6.0	8.2	+0.05	-0.10
20.72	1.14	27.49	6.1	8.2	-0.05	-0.10
29.25	1.10	27.28	6.8	8.4	-0.10	+0.10
30.15	1.06	27.38	5.7	7.9	-0.15	+0.20
30.75	1.15	27.30	5.7	7.8	+0.20	+0.10

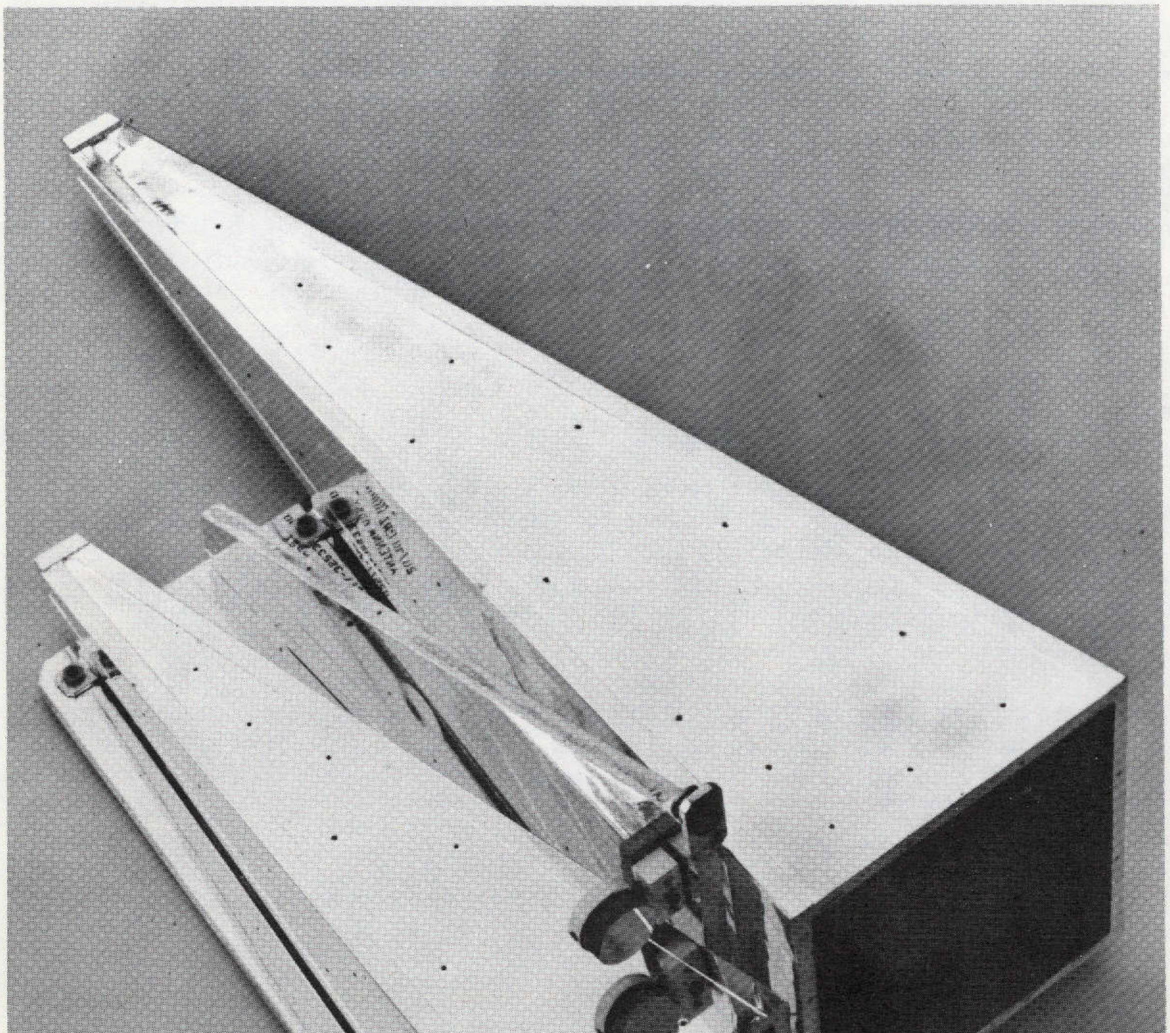


FIGURE 3-43. FLIGHT/PROTOTYPE MODEL 20/30 GHZ HORN ANTENNA ASSEMBLY (PHOTO 4R22374)

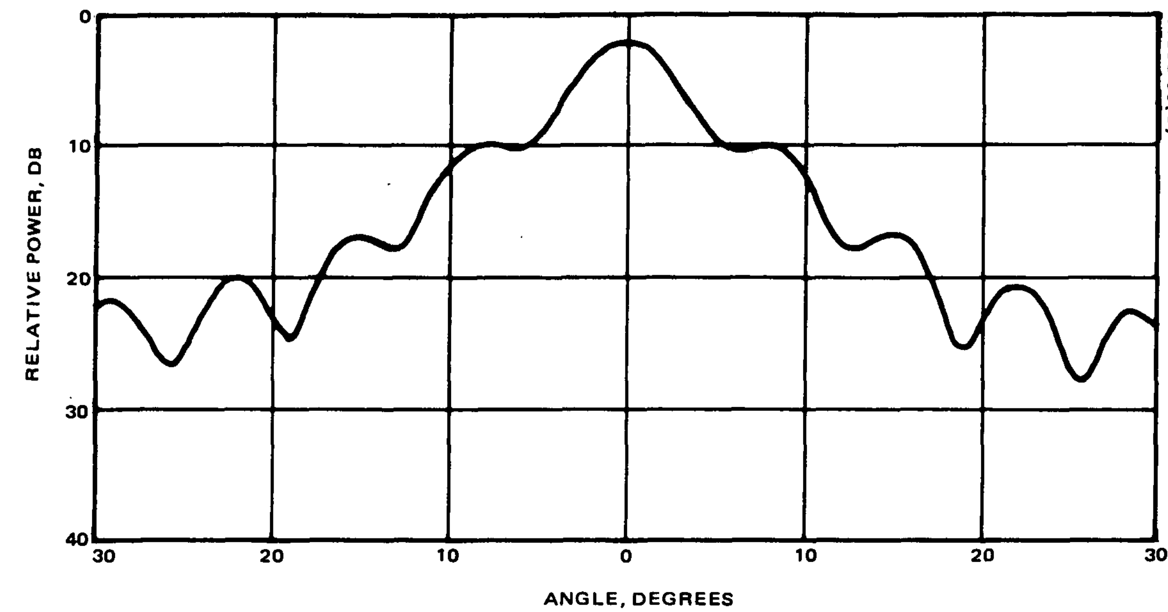


FIGURE 3-44. 20 GHz HORN ANTENNA E-PLANE PATTERN (20.15 GHz)

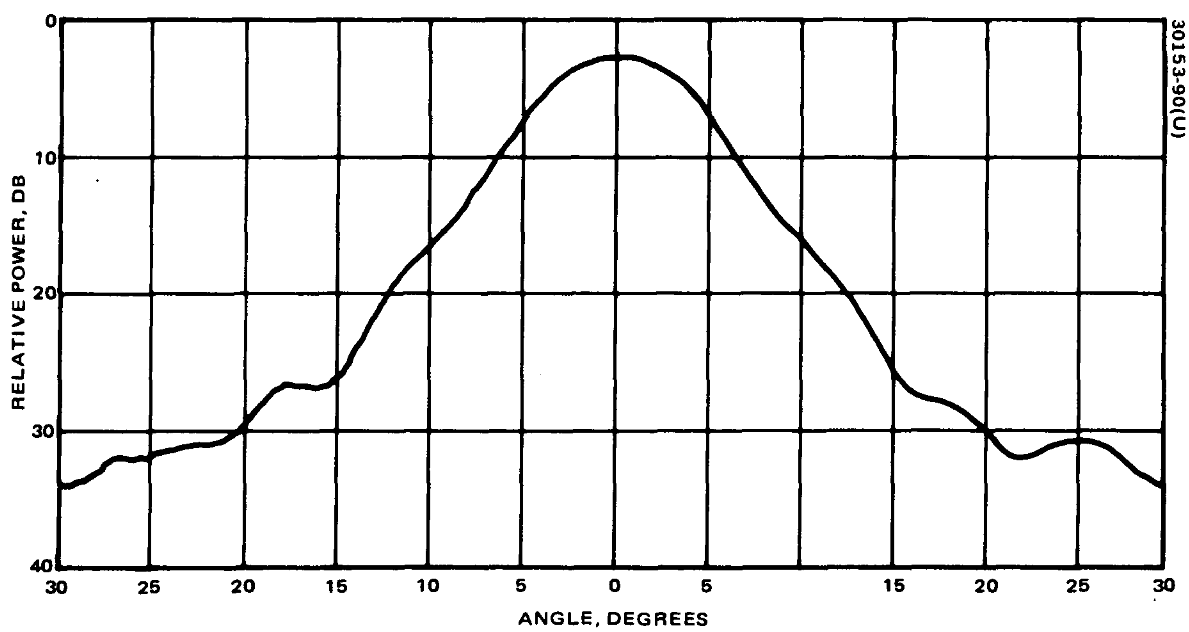


FIGURE 3-45. 20 GHz HORN ANTENNA H-PLANE PATTERN (20.15 GHz)

FIGURE 3-46. 30 GHz HORN ANTENNA E-PLANE PATTERN (30.15 GHz)

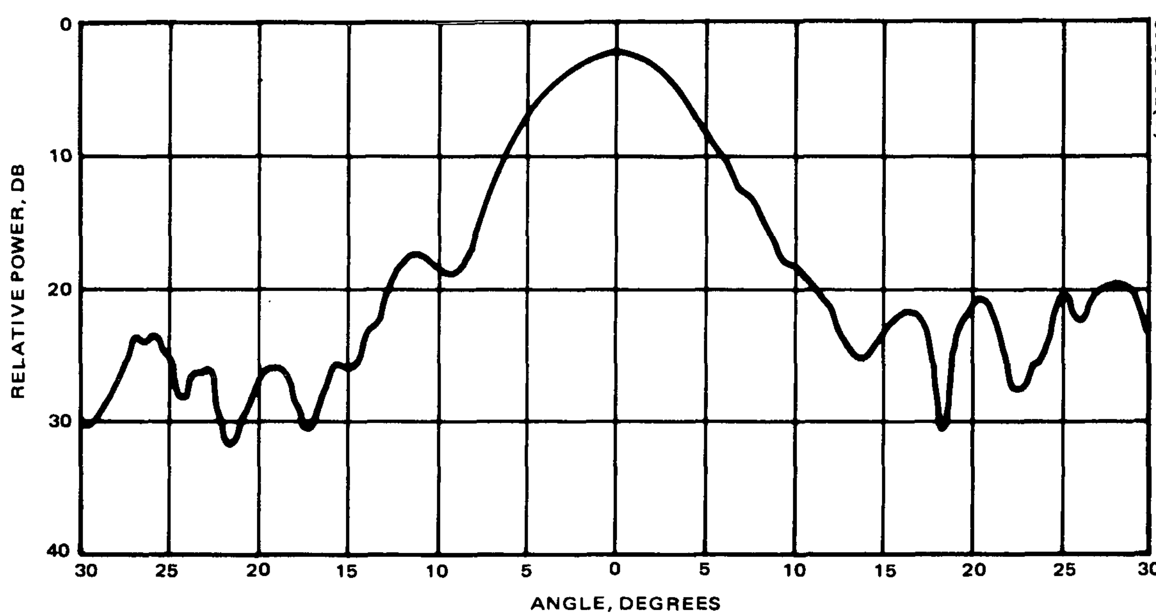


FIGURE 3-47. 30 GHz HORN ANTENNA H-PLANE PATTERN (30.15 GHz)

Several measures were incorporated into the design of the 20/30 GHz horn antenna assembly to minimize the thermal leakage through the two horn antennas. Fiberglass pads are bonded on both sides of the aluminum brackets used to mount each horn to their common assembly plate. This provides a measure of thermal isolation between the horns and the interior of the earth viewing module. In addition, the honeycomb beryllium-copper faceplate in the mouth and throat of both horns is gold plated to provide a high emissivity to all earth viewing surfaces of the horns. The remaining aluminum faceplate of both horns has a vacuum deposited aluminum coating to provide a low emissivity (less than 0.1) to all surfaces of the horns that are seen by the interior of the earth viewing module.

Finally, there is a thermal cover over the aperture of the horn antennas. The thermal covers consist of three layers of 1 mil Kapton, each with 1.5 mils of gloss white paint on one side. The painted side of the two inner sheets is outboard and of the outer sheet, inboard. Reversal of the outer sheet permits the Kapton to act as an untraviolet absorber and minimizes changes in solar absorptivity during mission life. Theoretical investigations indicate that the maximum expected heat transfer through the horn apertures are +3 watts in, due to direct solar radiation, and -2 watts out with no solar input. Bulk temperatures of the horns under these conditions are estimated to be +110° and +30°F, respectively. The effect of the cover on the horn electrical performance was very slight. Details on the configuration of the thermal cover may be found on the interface control drawing (Reference 3-5).

20/30 GHz PARABOLIC ANTENNA

The 18 inch diameter parabolic reflector and cylindrical extension of the reflector edge (called the tunnel) are fabricated separately and then riveted together. The parabola is fabricated from 0.062 inch thick aluminum sheet stock spun to the parabolic contour of the forming mandrel. The tunnel is fabricated from rolled 0.060 inch thick aluminum sheet stock out to the point where the mounting flange is attached. The 1.5 inch extension of the tunnel beyond the mounting flange is 0.020 inch thick aluminum. The RF active (inside) surfaces of the parabola and tunnel are polished to a mirror finish.

The gold plated aluminum scalar feed has four annular chokes on the outside wall and in close proximity to the aperture of its circular waveguide structure. The aluminum WR 34 rectangular waveguide from the antenna input to the circular waveguide adapter attached to the feed is also gold plated. A stainless steel tie rod support system keeps the feed properly located with respect to the parabola. The axial waveguide run is attached to the cylinder, top and bottom, after being shimmed for optimum feed placement. A permanently attached boresight reference mirror will permit alignment verification after installation in the spacecraft.

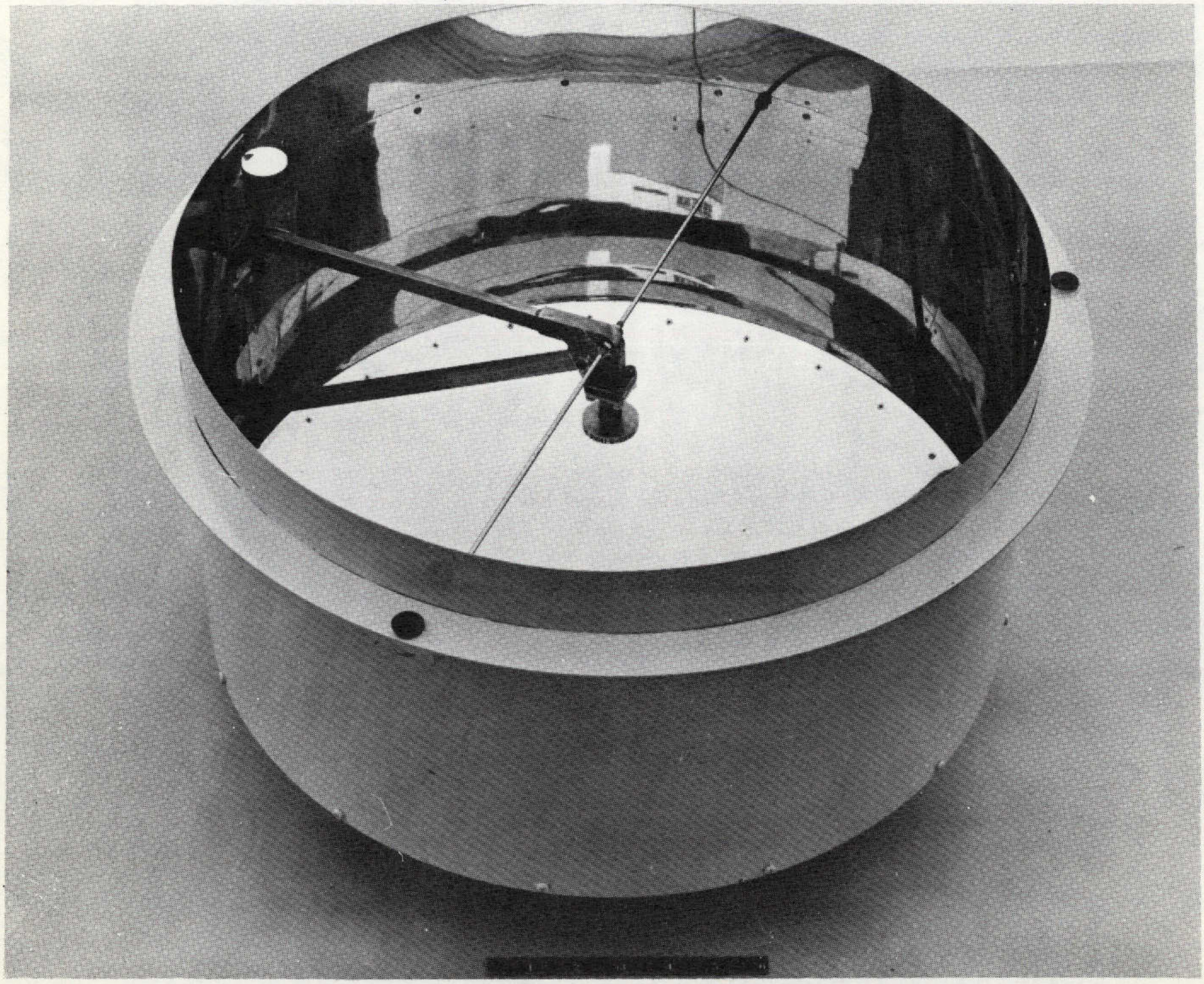


FIGURE 3-48. FLIGHT PROTOTYPE MODEL 20/30 GHz PARABOLIC ANTENNA (PHOTO 4R22372)

The aluminum construction enables the parabolic antenna assembly, including the reflector, tunnel, feed, tie rod support system, mounting flange, and boresight mirror, to possess good mechanical integrity with a total weight of 6.63 pounds. A photograph of the antenna is shown in Figure 3-48. More detail on its configuration may be found on the interface control drawing (Reference 3-6).

The parabolic reflector antenna is linearly polarized with the E plane aligned in the N-S direction. It operates at both 20.00 ±0.75 GHz and 30.00 ±0.75 GHz and utilizes a prime focus design, i.e., the feed is located at the focus of the reflector. The cylindrical extension of the reflector edge (called the tunnel) is required because the complete antenna assembly is located beneath the external surfaces of the spacecraft. The tunnel serves the primary purpose of reducing the RF energy level illuminating the interior of the spacecraft. The electrical performance of the parabolic antenna, over both frequency bands, is presented in Table 3-5. The E and H plane radiation patterns of the parabolic reflector antenna, at 20.15 and 30.15 GHz, are presented in Figures 3-49 through 3-52.

The open end of the cylinder is covered with a three layer thermal cover similar to that used on the horn antennas. Detail on the configuration of the thermal cover may be found on the interface control drawing (Reference 3-7). In addition to the thermal cover, further reduction in heat leak is provided by insulation pads at the mounting holes on the mounting flange and by providing layers of superinsulation between the antenna and the interior of the earth viewing module. Theoretical investigations indicate that the maximum expected heat transfer through the antenna is +2 watts in and -2 watts out. The attendant average dish temperatures are +150° and -50°F and average feed temperatures are +130° and +15°F.

COMSAT FILTERS

The purpose of the two COMSAT filters is to stop radiation that might affect the COMSAT 17.8 GHz receiver. As described in Section 2, the RF outputs of the modulator/power amplifier unit are carried in three waveguides: one 20 GHz, WR 42 waveguide, and one 20/30 GHz, WR 34 waveguide. The 20 GHz signals in the WR 42 waveguide pass through one of the two high pass Comsat filters to the 20 GHz horn antenna. The 20 and 30 GHz signals in the WR 34 waveguide pass through the other high pass Comsat filter to the parabolic antenna. Both filters are essentially identical in that they incorporate the identical section of reduced width waveguide to achieve essentially the same high pass filtering characteristics. The two filters differ only in the matching sections at each end required to match the reduced width waveguide to WR 42 waveguide in one case and to WR 34 waveguide in the other case. Drawings of the 20 GHz, WR 42 waveguide filter and the 20/30 GHz, WR 34 waveguide filter are shown in Figures 3-53 and 3-54, respectively.

The RF performance of the two filters over the frequencies of interest is shown in Table 3-6.

TABLE 3-5. 20/30 GHz PARABOLIC ANTENNA POSTENVIRONMENTAL PERFORMANCE

Frequency	VSWR, 1.3:1 maximum	Gain,* dB	Patterns (3 dB Beamwidth) E Plane,* degree	Patterns (3 dB Beamwidth) H Plane,* degree	Electrical Offset, 0.1 degree maximum
19.25	1.30	(36) 37.0	(2.0) 2.36	(2.0) 2.44	+0.07/+0.04
20.15	1.22	(37) 37.6	(2.0) 2.24	(2.0) 2.37	+0.06/+0.08
20.75	1.25	(36) 37.8	(2.0) 2.27	(2.0) 2.19	+0.06/+0.01
29.25	1.18	(38) 40.4	(1.4) 1.58	(1.4) 1.61	+0.09/+0.01
30.15	1.11	(39) 40.1	(1.4) 1.56	(1.4) 1.62	+0.07/+0.03
30.75	1.07	(38) 40.3	(1.4) 1.54	(1.4) 1.58	+0.05/0
					+AZ /+EL
					$+\theta$ /$+\phi$

*( ) indicate minimum.

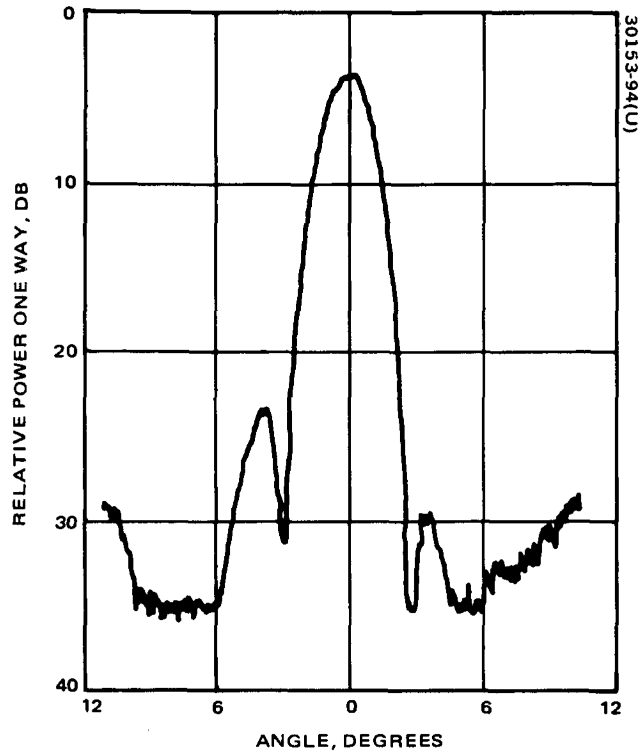


FIGURE 3-49. PARABOLIC ANTENNA E-PLANE PATTERN (20.15 GHz)

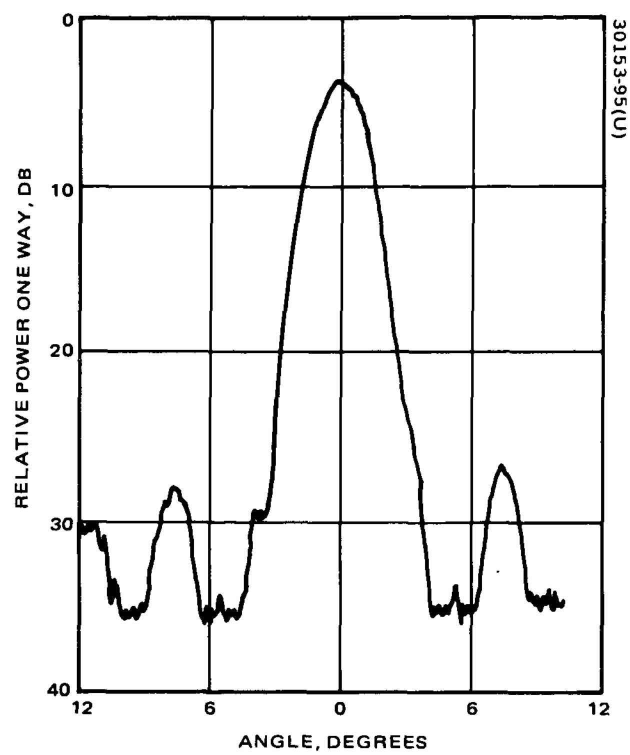


FIGURE 3-50. PARABOLIC ANTENNA H-PLANE PATTERN (20.15 GHz)

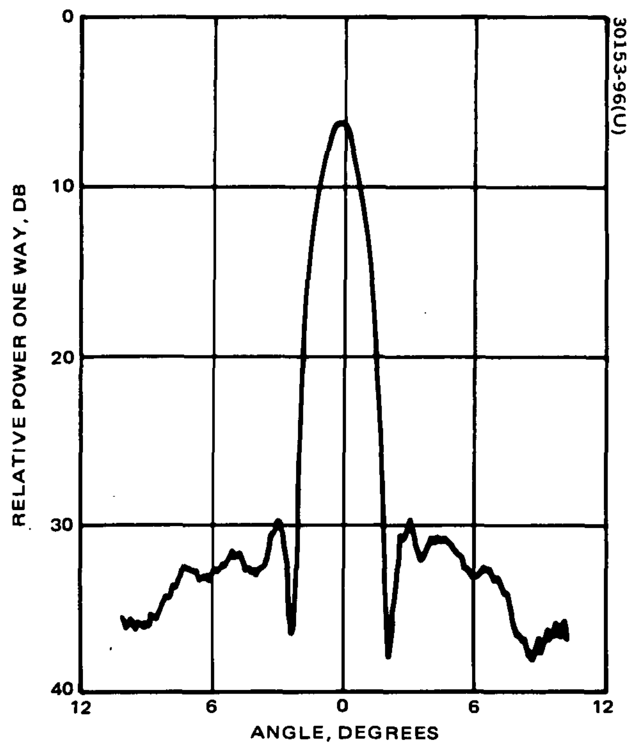


FIGURE 3-51. PARABOLIC ANTENNA E-PLANE PATTERN (30.15 GHz)

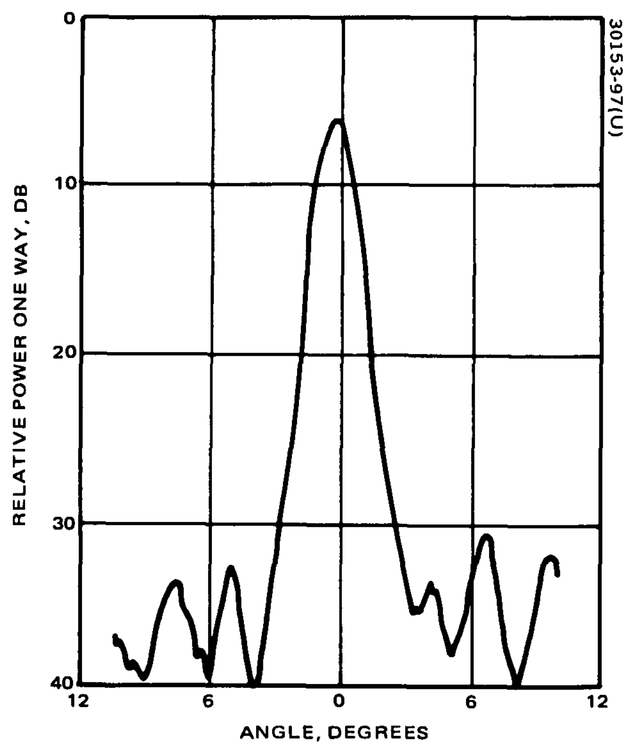


FIGURE 3-52. PARABOLIC ANTENNA H-PLANE PATTERN (30.15 GHz)

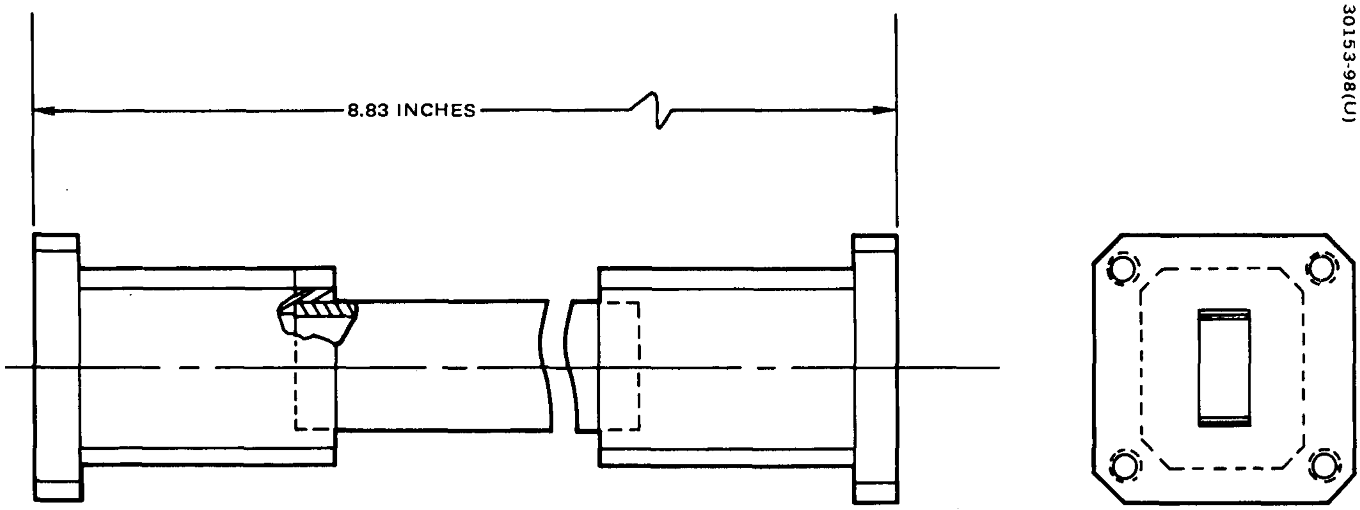


FIGURE 3-53. COMSAT FILTER FOR WR 42 (20 GHz) WAVEGUIDE

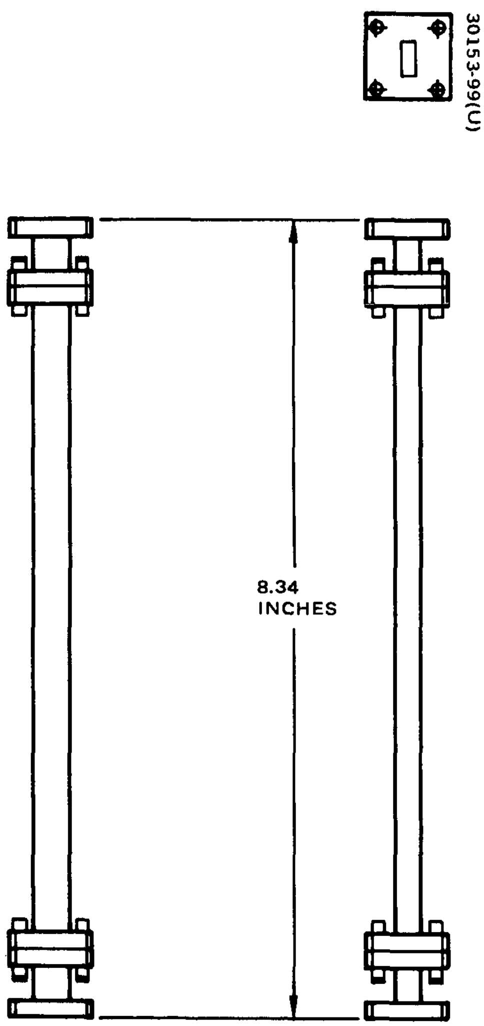


FIGURE 3-54. COMSAT FILTER FOR WR 34 (20/30 GHz) WAVEGUIDE

TABLE 3-6. RF PERFORMANCE OF COMSAT FILTERS

Filter Matched to Indicated Waveguide Type	Over Bandwidth 19.25 to 20.75 GHz		Over Bandwidth 29.25 to 30.75 GHz		Attenuation at 17.8 GHz, dB
	Maximum Insertion Loss, dB	Maximum VSWR	Maximum Insertion Loss, dB	Maximum VSWR	
WR 34	0.4	1.35	0.4	1.22	Greater than 84*
WR 42	0.47	1.38	---	---	Greater than 70*

*The attenuation was greater than the measurement limitation.

REFERENCES

3-1 GSFC Drawing G-460F-023, "ATS-F Millimeter Wave Experiment Interface Control Drawing, RF Multiplier," Revision D, 24 May 1972.

3-2 Hughes Drawing 3253301-200, "Interconnection Diagram, Millimeter Wave Experiment for ATS-F," 26 October 1972.

3-3 GSFC Drawing G-460F-024, "ATS-F Millimeter Wave Experiment Interface Control Drawing, 20/30 GHz Modulator/Power Amplifier," Revision F, 25 August 1972.

3-4 GSFC Drawing G-460F-026, "ATS-F Millimeter Wave Experiment Interface Control Drawing, 20/30 GHz Horn Antennas," Revision E, 24 May 1972.

3-5 GSFC Drawing G-460F-090, "ATS-F Millimeter Wave Experiment Interface Control Drawing, Thermal Cover, 20/30 GHz Horn Antennas," Revision D, 24 May 1972.

3-6 GSFC Drawing G-460F-025, "ATS-F Millimeter Wave Experiment Interface Control Drawing, 20/30 GHz Parabolic Antenna," Revision D, 25 May 1972.

3-7 GSFC Drawing G-460F-030, "ATS-F Millimeter Wave Experiment Interface Control Drawing, Thermal Cover, 20/30 GHz Parabolic Antenna," Revision C, 24 May 1972.

4. QUALIFICATION TEST SUMMARY

INTRODUCTION

The purpose of this section is to summarize the qualification tests on the experiment and the results of those tests. Since there was no separate prototype model, qualification tests were performed on the flight/protytype model. With the exception of certain tests on elements of the TWTAs, all of the components of the flight/prototype experiment were subjected to qualification level tests in accordance with the GSFC approved test plans, which, in turn, were based on the GSFC environmental test specification (Reference 4-1). In the case of those TWTA elements exempted from certain qualification level tests, acceptance level tests were performed, again in accordance with GSFC approved test plans.

Subsequent paragraphs of this section will discuss in turn a summary of the test plans, the electronic subsystem tests, the antenna tests, the TWT and TWTA tests, and EMI tests on the electronic subsystem.

SUMMARY OF THE TEST PLANS

The basis for all testing of the experiment was the General Test Plan (Reference 4-2) which was approved by GSFC. It defined the requirements for in-process tests, engineering tests, and formal qualification and acceptance tests. Subsidiary to this General Test Plan was a series of detailed test plans and procedures which controlled the tests performed on all of the individual items of equipment which make up the experiment.

Each functional module of the experiment had associated with it a released test procedure which established the in-process test requirements. These test procedures were approved by the head of the responsible engineering activity at Hughes. In general the procedures covered performance tests and thermal tests only. Each flight module was subjected to the tests defined in the procedures with test area surveillance being provided by Hughes Quality Control personnel.

Each unit and major assembly of the experiment had associated with it a released test plan or procedure which established the formal test requirements for it. In general these documents covered performance tests and the

TABLE 4-1. TEST PLANS AND PROCEDURES FOR MILLIMETER WAVE EXPERIMENT UNITS AND MAJOR ASSEMBLIES

Test Plan or Procedure	Hughes Project Manager Approval	GSFC Approval	Reference
Electronic Subsystem Qualification Test Plan	X	X	4-3
Electronic Subsystem EMI Test Plan	X	X	4-4
Long Form Test Procedure	X	X	4-5
Short Form Test Procedure	X	X	4-6
RF Multiplier Test Plan	X	X	4-7
Modulator/Power Amplifier Test Plan	X	X	4-8
20 GHz TWTA Acceptance Test Plan	X	X	4-9
20 GHz TWT Power Supply Test Specification	X		4-10
20 GHz TWT Power Supply Qualification Test Procedure	X		4-11
30 GHz TWTA Acceptance Test Plan	X	X	4-12
30 GHz TWT Power Supply Test Specification	X		4-13
30 GHz TWT Power Supply Qualification Test Procedure	X		4-14
Horn Antenna Qualification Test Plan	X	X	4-15
Parabolic Antenna Qualification Test Plan	X	X	4-16
20 GHz TWT Acceptance Test Procedure	X		4-17
20 GHz TWT Qualification Test Procedure	X		4-18
30 GHz TWT Acceptance Test Procedure	X		4-19
30 GHz TWT Qualification Test Procedure	X		4-20

complete environmental tests. Table 4-1 lists the unit and major assembly test plans and procedures and indicates the level of approval that each received. Each item of the experiment was subjected to the tests defined in the plans and procedures with tests witnessed by Hughes Quality Control personnel.

The environmental tests performed were in accordance with the GSFC environmental test specification S-320-ATS-2D (Reference 4-1), with certain modifications approved by GSFC. A summary of the environmental tests received by the units and major assemblies is given in Table 4-2. The specific environmental conditions are described in the following paragraphs.

Storage Temperature

The storage temperature environment for all units except the antennas consisted of a 6 hour soak at -30°C followed by a 6 hour soak at 60°C with the units not operating. A performance test was conducted at the conclusion of the exposure. In the case of antennas, storage temperature and thermal-vacuum tests were combined since the temperatures used in thermal-vacuum equaled or exceeded the storage temperature limits specified by S-320-ATS-2D.

Operating Temperature

The operating temperature environment for the RF multiplier, all TWT power supplies, and the qualification model TWTs consisted of a 6 hour period at -10°C followed by a 6 hour period at 50°C with the unit operating. Three cold starts were performed during the low temperature period. In the case of the modulator/power amplifier, the temperature profile was the same except that the low temperature was set at -5°C. This was done to avoid a second exposure of -10°C on the TWT power supplies because of encapsulant problems that were attributed to low temperature exposure.

Vibration

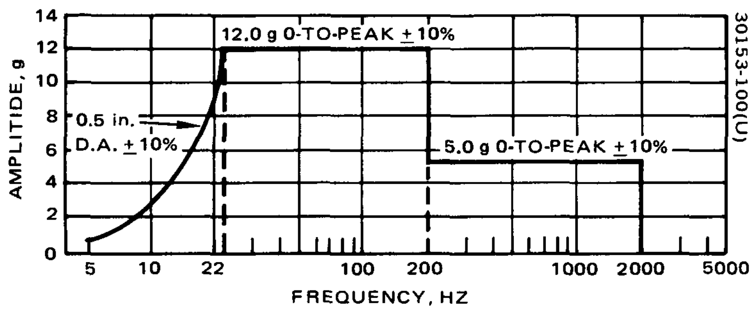
All items of the experiment, except the TWTs having an F serial number, were subjected at least once to the full qualification level vibration. In addition, the qualification model TWTs (designated with a Q serial number) were subjected at least once to this level. Qualification vibration included three axes of swept sinusoidal vibration at a sweep rate of 2 octaves per minute with a profile as shown on Figure 4-1a) and 4 minutes of exposure in each axis to a random motion vibration having a profile as shown on Figure 4-2a).

Since vibration failures were encountered in both the RF multiplier and the modulator/power amplifier, vibration retest was required. In order to avoid possible fatigue problems in these flight/prototype units, a modified vibration test was agreed to for the retest. It consisted of 3 axes of swept sinusoidal vibration at a sweep rate of 4 octaves per minute with a profile as shown on Figure 4-1b) and 2 minutes of exposure in each axis to a random motion vibration having a profile as shown on Figure 4-2a).

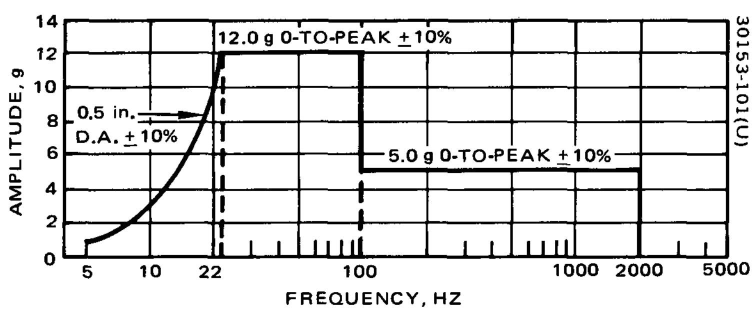
TABLE 4-2. SUMMARY OF MILLIMETER WAVE EXPERIMENT ENVIRONMENTAL EXPOSURE

Equipment	Qualification Storage Temperature	Qualification Operating Temperature	Qualification Vibration	Modified Qualification Vibration	Acceptance Vibration	Qualification Thermal-Vacuum	Acceptance Thermal-Vacuum
RF multiplier	X	Twice	X	X	Z-Z axis Random		
Modulator/power amplifer without TWTAs	X		X	X			
Modulator/power amplifer with TWTAs					Z-Z axis Random		
RF multiplier and modulator/ power amplifier including TWTAs		X				X	
20/30 GHz horn antennas	Note 1		X			Note 1	
20/30 GHz parabolic antennas	Note 1		X			Note 1	
20 GHz TWTs, F1, F2, and F3					X		X
20 GHz TWT, Q3	X	X	X			X	
20 GHz TWT power supplies, F2 and F3		X	X				
20 GHz TWT power supply, F1	X	X	X				
20 GHz TWTA, F3 (TWT F3 and power supply F3)							X
30 GHz TWTs, F1 and F2					X		X
30 GHz TWT, Q1	X	X	X	Sine, two axes		X	X
30 GHZ TWT power supply, F1 and F2		X	X				
30 GHz TWT power supply, F3	X	X	X				
30 GHz TWTA, F3 (TWT Q1 and power supply F3)							X

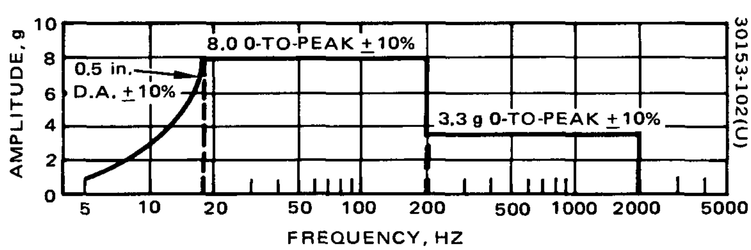
Note 1: Antenna storage temperature and thermal-vacuum tests combined.



a) **DESIGN QUALIFICATION SWEEP RATE: 2 oct/min**

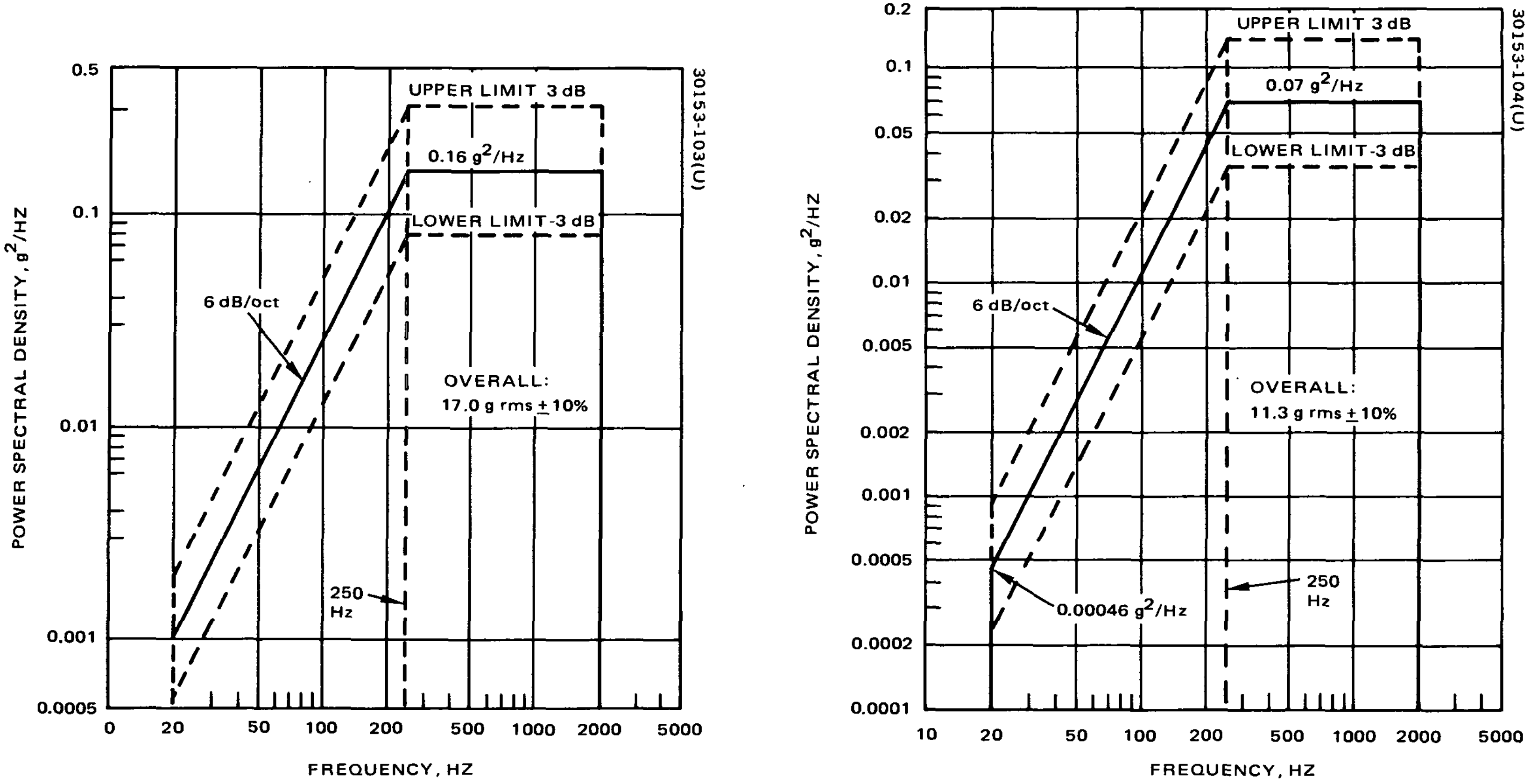


b) **MODIFIED QUALIFICATION SWEEP RATE: 4 oct/min**



c) **FLIGHT ACCEPTANCE SWEEP RATE: 4 oct/min**

FIGURE 4-1. SWEPT SINUSOIDAL VIBRATION PROFILES



a) **DESIGN QUALIFICATION**

b) **FLIGHT ACCEPTANCE**

FIGURE 4-2. RANDOM MOTION VIBRATION POWER SPECTRAL DENSITY PROFILE

All flight TWTs (designated with an F serial number) were subjected to acceptance level vibration. This consisted of 3 axes of swept sinusoidal vibration at a sweep rate of 4 octaves per minute with a profile as shown on Figure 4-1c) and 2 minutes of exposure in each axis to a random motion vibration having a profile as shown on Figure 4-2b). In addition both the RF multiplier and the modulator/power amplifier in final flight configuration received 2 minutes of exposure to random motion vibration in axis Z-Z only to this acceptance level.

Thermal-Vacuum

All items of the experiment were subjected to thermal-vacuum tests. The RF multiplier, the modulator/power amplifier with its full complement of flight TWTAs, and the two qualification TWTs as separate items were tested while operating under the full qualification level thermal-vacuum conditions. The test consisted of a pump down to a pressure of 1×10^{-5} Torr or less, then a decrease in temperature to $-5^{o}C$ which was maintained for 24 hours, then an increase in temperature to $50^{o}C$ which was maintained for 24 hours, and then a return to ambient conditions. Functional tests were performed at room temperature and the two temperature extremes. In addition, the combination of the RF multiplier and modulator/power amplifier was stabilized at $5^{o}C$ and $35^{o}C$ while under vacuum and functionally tested to obtain a calibration of performance at the expected spacecraft extreme temperatures.

The antennas received a similar thermal-vacuum cycle in a non-operating state. Although the vacuum conditions and time were the same, the temperature extremes were extended beyond the required qualification limits to take into account the expected temperature extremes of these items in orbit.

The spare TWTAs received an extended thermal-vacuum test under acceptance level temperature conditions. The cycle consisted of chamber pump down to 1×10^{-5} Torr or less, then a decrease in temperature to $5^{o}C$ which was maintained for 48 hours, then a temperature transition to $35^{o}C$ which was maintained for 48 hours, and then a return to ambient conditions. Functional tests were performed at room temperature and at the two temperature extremes.

ELECTRONIC SUBSYSTEM TESTS

The electronic subsystem of the experiment consists of the RF multiplier unit and the 20/30 GHz modulator/power amplifier unit. Tests on the subsystem were performed with generally three levels of subsystem assembly: 1) the RF multipliers alone, 2) a combination of the RF multiplier and the modulator/power amplifier with the TWTAs replaced with mass models, and 3) a combination of the RF multiplier and the modulator/power amplifier in full flight configuration.

Testing procedures for the subsystem were contained in three documents, the RF Multiplier Test Plan and Specification (Reference 4-7), the Modulator/Power Amplifier Unit Test Plan and Specification (Reference 4-8), and the Electronic Subsystem Qualification Test Plan (Reference 4-3). The RF Multiplier Test Plan established the tests at the RF multiplier unit level including the performance tests at nominal supply voltages, at a high supply voltage of 31 volts dc and at a low supply voltage of 24.5 volts dc, the operating temperature tests including cold start tests, and the frequency stability and spectral purity tests. The Modulator/Power Amplifier Test Plan established the tests at the subsystem level including the performance tests at nominal supply voltages, at a high supply voltage of 32 volts dc, and at a low supply voltage of 25.5 volts dc, the operating temperature tests including cold start tests, and the tests to be performed when the TWTAs were replaced by mass models. The Electronic Subsystem Qualification Test Plan defines the environmental tests including storage temperature, operating temperature, vibration, and thermal-vacuum.

A chronological sequence of the tests performed on the electronic subsystem is given in Table 4-3. A cross-reference matrix of these tests as they relate to various qualification test, acceptance test, and engineering test conditions is given in Table 4-4. Also included in the two tables are the EMI tests on the subsystem and these tests are discussed at the end of this section. The data acquired during the subsystem tests, particularly that acquired in the last series (when in the complete flight configuration), formed the basis for the experiment performance data reported in Section 2 of this report.

Problems encountered in subsystem testing were primarily associated with vibration exposure. Inspection of the RF multiplier unit after completion of the vibration test revealed structural fractures in the mounting flanges of two modules mounted on the upper deck inside the unit. In addition, a crack was noted in one semirigid coax cable and poor contact was found in one coax connector. Structural redesign was performed and the unit was reworked and successfully passed a vibration retest to a modified qualification level.

In the case of the modulator/power amplifier unit a number of bracket and semirigid coax cable failures were experienced. Structural redesigns were accomplished, bonding processes were improved, coaxial cable routing was extensively improved, and flexible coax cables were substituted for four of the semirigid lines. Two vibration induced failures were experienced in the phase modulators. This resulted in internal modifications to all four phase modulators and these were individually vibration tested successfully. After the modulator/power amplifier was modified with the various design improvements, it was successfully vibration tested to modified qualification levels.

During an engineering evaluation test under thermal-vacuum conditions (test sequence number 14 on Table 4-3), the 20 GHz TWTA went off and could not subsequently be commanded on under vacuum conditions. This was one of the four high voltage breakdown problems experienced during the program. These problems are discussed in Section 5 of this report.

TABLE 4-3. MILLIMETER WAVE EXPERIMENT CHRONOLOGICAL TEST MATRIX

Sequence Number	Test Date	Configuration Description	Test Description: Test Type	Test Description: Test Level	Remarks
1	9/30/71	RF multiplier	Vibration three axes sine and random	Qualification	Module flange fractures. Cracks in coaxial cable.
2	10/8/71	RF multiplier	Operating temperature	Qualification	
3	12/13-14/71	Modulator/amplifier with mass models of four TWTs and power supplies	Vibration Y-Y axis sine and random	Qualification	Broken wire and coaxial cable clamp loosened.
4	12/13/71	Modulator/amplifier with mass models of four TWTs and power supplies	Vibration Z-Z axis sine and random	Qualification	Bracket loosened and failures in phase modulators F2 and F4.
5	12/27/71	F2 and F4 phase modulators	Vibration three axes sine	Modified Qualification	
6	12/30/71	Modulator/amplifier with mass models of four TWTs and power supplies	Vibration X-X axis sine	Qualification	Two cables and bracket mechanical failure. Phase modulator F1 intermittent.
7	1/3/72	Modulator/amplifier with mass models of four TWTs and power supplies	Thermal-vacuum	Engineering	Two new flight cables. F1 phase modulator still intermittent.
8	1/4/72	RF multiplier	Storage temperature	Qualification	
9	1/4/72	Modulator/amplifier with mass models of four TWTs and power supplies	Storage temperature	Qualification	

Table 4-3 (continued)

Sequence Number	Test Date	Configuration Description	Test Description		Remarks
			Test Type	Test Level	
10	1/15/72	Modulator/amplifier with mass models of TWTs and power supplies and F1 and F2 phase modulators	Vibration X-X, random vibration X-X, sine vibration Y-Y, Z-Z, sine and random	Qualification Modified Qualification Modified Qualification	Circulator switch cover loosened during vibration in Y-Y axis.
11	1/18/72	Modulator/amplifier with mass models of TWTs and power supplies and F1 and F3 phase modulators	Thermal-vacuum	Engineering	
12	1/21/72	F1 and F3 phase modulators	Vibration three axes sine and random	Modified Qualification	F3 phase modulator intermittent.
13	1/26/72	F3 phase modulator	Vibration vertical axis of phase modulator	Modified Qualification	
14	2/2/72	Modulator/amplifier with one 20 GHz qualification model TWT and power supply. One 30 GHz engineering model TWT and power supply. Mass models of the other two TWTs and power supplies.	Thermal-vacuum	Engineering	20 GHz qualification model TWT would not stay on at 14°F.
15	2/4/72	Modulator/amplifier with one 20 GHz qualification model TWT and power supply. One 30 GHz engineering model TWT and power supply. Mass models of the other two TWTs and power supplies.	Thermal-vacuum	Engineering	

Table 4-3 (continued)

Sequence Number	Test Date	Configuration Description	Test Description		Remarks
			Test Type	Test Level	
16	2/17/72	RF multiplier	Vibration retest three axes sine and random	Modified Qualification	With master oscillator replaced with nonflight units.
17	2/28/72	RF multiplier	Operating temperature	Qualification	
18	3/20/72	Electronic subsystem with all flight components but without antennas and spacecraft waveguide	Subsystem adjustments	Engineering	
19	6/13/72	Electronic subsystem with all flight components but without antennas and spacecraft waveguide	Performance	Qualification	
20	6/16/72	Electronic susbsystem with all flight components but without antennas and spacecraft waveguide	Operating temperature	Qualification	Power monitor failed.
21	6/21/72	Electronic subsystem with all flight components but without antennas and spacecraft waveguide	Operating temperature	Qualification	
22	6/27/72	Electronic subsystem with all flight components but without antennas and spacecraft waveguide	Electromagnetic interference	Qualification	Conducted emission CE 01 and 03 tests.
23	6/27/72	Electronic subsystem with all flight components but without antennas and spacecraft waveguide	Electromagnetic interference	Qualification	Radiation tests RE 02.
24	6/29/72	Electronic subsystem with all flight components but without antennas and spacecraft waveguide	Electromagnetic interference	Qualification	Conducted susceptibility tests CS 01.

Table 4-3 (continued)

Sequence Number	Test Date	Configuration Description	Test Description		Remarks
			Test Type	Test Level	
25	7/6/72	RF multiplier	Vibration Z-Z axis random	Acceptance	
26	7/6/72	Modulator/amplifier	Vibration Z-Z axis random	Acceptance	
27	7/11/72	Electronic subsystem with all flight components but without antennas and spacecraft waveguide	Post-vibration	Acceptance	
28	7/12/72	Electronic subsystem with all flight components but without antennas and spacecraft waveguide	Thermal-vacuum	Qualification	
29	7/17/72	Electronic subsystem with all flight components but without antennas and spacecraft waveguide	Performance	Acceptance	
30	7/21/72	Electronic subsystem with all flight components but without antennas and spacecraft waveguide	Receiver compatibility	Engineering	
31	7/31/72	Electronic subsystem with all flight components but without antennas and spacecraft waveguide	Electromagnetic interference	Qualification	Radiated susceptibility tests RS 03.

TABLE 4-4. MILLIMETER WAVE EXPERIMENT TEST/CONFIGURATION MATRIX

Configuration	Qualification: Performance	Qualification: Vibration Full Qualification	Qualification: Vibration Modified Qualification	Qualification: Storage Temperature	Qualification: Operating Temperature	Qualification: Thermal-Vacuum	Qualification: EMI	Acceptance: Vibration, Z-Z Random Only	Acceptance: Performance	Engineering: Subsystem Adjustment	Engineering: Receiver Compatibility	Engineering: Thermal-Vacuum
Modulator/amplifier with mass models of four TWTs and power supplies		3,4, 6		9								7
F1 and F3 phase modulators			12									
F2 and F4 phase modulators			5									
Modulator/amplifier with mass models of TWTs and power supplies and F1 and F3 phase modulators												11
Modulator/amplifier with mass models of TWTs and power supplies and F1 and F2 phase modulators		10	10									
F3 phase modulator			13									
Modulator/amplifier with one 20 GHz qualification model TWT and power supply. One 30 GHz engineering model TWT and power supply. Mass models of the other two TWTs and power supplies.												14, 15
RF multiplier		1	16	8	2, 17			25				
Electronic subsystem with all flight components, but without antennas and spacecraft waveguide	19				20, 21	28	22,23,24,31	26	27, 29	18	30	

NOTE: Numbers refer to chronological matrix of Table 4-3.

A final problem associated with subsystem testing occurred during the final thermal-vacuum test. During transition from cold soak to hot soak, the 20 GHz circulator switch and the 30 GHz circulator switch each changed state, either partially or completely, at different times within a period of about 3 minutes. Considerable audible noise from the chamber control solenoid valves was also noted at this time. The phenomenon could not be repeated while the subsystem was in the chamber.

Subsequent investigation of the problem revealed that the phenomenon could be reproduced by injection of pulses of certain widths and amplitudes directly into the command lines associated with the switches. It was decided, though not absolutely proven, that such pulses from the chamber control solenoid circuits were coupled into the unshielded command lines from the bench test equipment. The susceptibility of the command circuits was characterized by a series of tests. It was found that pulses of at least 6 volts and at least 100 microseconds at the command interface circuit were required to begin to cause the effect. It was concluded that, with the spacecraft command cable shielded and with the cable between the modulator/power amplifier and the RF multiplier shielded, the likelihood of pickup of pulses of this magnitude would be extremely small in the spacecraft. For this reason the extensive task of desensitizing the command interface circuits was not undertaken.

A special test was performed on the subsystem with the ground receiver built by another contractor. This test successfully demonstrated the compatibility between these two elements of the complete millimeter wave experiment system.

ANTENNA TESTS

The qualification tests on the antennas for the experiment were conducted in accordance with the 20/30 GHz Horn Antenna Qualification Test Plan (Reference 4-15) and the 20/30 GHz Parabolic Antenna Qualification Test Plan (Reference 4-16). These plans covered the performance testing, vibration testing, and thermal-vacuum testing of the antennas. Antenna pattern tests on the horn antennas were performed in an anechoic chamber, and pattern tests on the parabolic antenna were performed on an outdoor antenna range. No performance tests could be practically conducted while the antennas were in the thermal-vacuum chamber. A complete report of the antenna qualification tests was prepared (Reference 4-21) and submitted to GSFC.

No problems were experienced in any of the qualification tests on the horn antennas. A structural problem was experienced, however, in the feed waveguide on the parabolic antenna during vibration testing. Structural redesign was accomplished, the antenna was reworked, and it successfully passed vibration retest to the full qualification levels.

TWTA TESTING

This subsection describes the qualification and acceptance testing performed on the 20 and 30 GHz TWTs the 20 and 30 GHz TWT power supplies, and the combinations of these into 20 and 30 GHz TWTAs. TWTs were tested in accordance with qualification test procedures and acceptance test procedures (References 4-17 through 4-20). Power supplies were tested in accordance with test specifications and qualification test procedures (References 4-10, 4-11, 4-13, and 4-14). These latter documents were also used for testing the flight model TWTAs. Spare TWTAs were subjected to acceptance level thermal-vacuum tests in accordance with the TWTA Acceptance Test Plans (References 4-9 and 4-12) in addition to the same tests as the flight models. Table 4-5 presents the qualification, acceptance, and engineering tests performed on the TWTs power supplies and TWTAs in more detail than was given in Table 4-2.

Qualification test reports have been prepared and submitted to GSFC (References 4-22 and 4-23) covering the qualification tests on the 20 GHz TWT (Hughes designation 268H) and on the 30 GHz TWT (Hughes designation 254H). Subsequent to the submittal of the reports, each of these TWTs experienced a failure at the TWTA level in thermal-vacuum testing. The 20 GHz TWT (268H serial Q3) had a broken collector lead at the point of exit from the TWT body (probably due to handling) and this resulted in a voltage breakdown. The TWT was repaired and was in the process of being retested for possible use as a spare when a test equipment failure caused irreparable damage to it. The 30 GHz TWT (254H serial Q1) had a high voltage breakdown in the encapsulant surrounding the collector. This fault was repaired but the rework process required a slight configuration modification. After this it was subjected to the modified qualification level sinusoidal vibration (Figure 4-1 b) in two axes and acceptance level thermal-vacuum tests, after which it was judged satisfactory for use as a flight spare. No problems were encountered in testing the flight TWTs (those designated with F serial numbers).

Two component failures were experienced in TWT power supply testing. The first occurred in the 20 GHz TWT power supply, serial number F3, during vibration testing. A transistor in the filament supply shorted due to a workmanship defect. The fault was repaired and subsequent testing was entirely normal. The second failure was a switching transistor in the high voltage converter of 30 GHz TWT power supply, serial number F3. This was replaced and testing proceeded. The cause of the failure has not definitely been established, but it is quite possible that it is related to a high voltage breakdown which was subsequently experienced in the high voltage encapsulant of both this power supply and the previously mentioned 254H, Q1 TWT which was integrated with it.

The voltage breakdown failure in the F3 30 GHz power supply and a similar failure in the F1 30 GHz power supply are definitely related. This problem along with the corrective actions are discussed in Section 5. In

TABLE 4-5. TWTA TEST MATRIX

Test Description	20 GHz TWTA Q TWT Q3, PS F3	20 GHz TWTA F1 TWT F1, PS F1	20 GHz TWTA F2 TWT F2, PS F2	20 GHz TWTA F3 TWT F3, PS F3	30 GHz TWTA F1 TWT F2, PS F1	30 GHz TWTA F2 TWT F1, PS F2	30 GHz TWTA F3 TWT Q1, PS F3
TWT Qualification Tests							
Pre-environmental performance	X						X
Sine vibration	X						X
Postsine vibration RF performance	X						X
Random vibration	X						X
Postrandom vibration RF performance	X						X
Storage temperature	X						X
Poststorage RF performance	X						X
Operating temperature	X						X
Thermal-Vacuum	X						X
Post-thermal vacuum performance	X						X
Humidity	X						X
Final performance	X						X
TWT Acceptance Tests							
Pre-environmental performance		X	X	X	X	X	
Sine vibration		X	X	X	X	X	X
Postsine vibration performance		X	X	X	X	X	X
Random vibration		X	X	X	X	X	
Postrandom vibration performance		X	X	X	X	X	
Thermal-vacuum		X	X	X	X	X	X
Post-thermal-vacuum performance		X	X	X	X	X	X
Final performance		X	X	X	X	X	X
Power Supply Tests							
In-process and performance	X	X	X	X	X	X	X
Qualification sine and random vibration	X	X	X	X	X	X	X
Postvibration performance	X	X	X	X	X	X	X
Qualification storage temperature	X			X	X		
Poststorage performance	X			X	X		
TWTA Tests							
Pre-encapsulation performance	X	X	X	X	X	X	X
Postencapsulation and operating temperature	X	X	X	X	X	X	X
Vacuum	X	X	X	X	X	X	X
Acceptance thermal-vacuum				X			X
Final performance		X	X	X	X	X	X

both of these power supplies the encapsulated high voltage modules were replaced by newly fabricated modules, and the testing of the power supplies and TWTs proceeded without problems thereafter.

SUBSYSTEM EMI TESTING

Electromagnetic interference measurements were made on the electronic subsystem in accordance with the EMI Test Plan (Reference 4-4). The purpose of the measurements were to determine the EMI characteristics of the experiment but not necessarily to ensure that it met a prescribed set of requirements. Examination of the data collected would be performed by the ATS-F spacecraft program office and corrective actions would be directed if necessary.

The test plan was based on specific test methods extracted from MIL-STD-462 (Reference 4-24) as shown on Table 4-6. The test was performed and data was submitted to GSFC. Table 4-7 summarizes the specific data points which exceeded the requirements of MIL-STD-461A (Reference 4-25). Special tests were also performed of radiated emissions in the region of the Comsat receiver frequency, and the results are given in Table 4-8. This test was performed without the Comsat filters attached to the experiment.

TABLE 4-6. ELECTROMAGNETIC INTERFERENCE TEST PLAN SUMMARY

Electromagnetic Interference Test	Method	Frequency	Objective
Conducted emission	CE 01	30 Hz to 20 kHz	To measure narrowband conducted emissions on each power lead.
Conducted emission	CE 03	20 kHz to 50 MHz	To measure broadband and narrowband conducted emissions on each power lead.
Conducted susceptibility	CS 01	30 Hz to 50 kHz	To determine susceptibility of the system to injected voltages on the power leads.
Conducted susceptibility	CS 06	10 microsecond pulses	To determine system susceptibility to spike voltage injected on the power leads.
Radiated emissions	RE 02	14 kHz to 10 GHz	To measure electric field radiated emissions from equipment, including cables.
Radiated susceptibility	RS 03	14 kHz to 10 GHz	To determine system susceptibility to radiated electric fields.

TABLE 4-7. EMI TEST RESULTS SUMMARY

Test Method	Emissions or Susceptibility Which Exceeded MIL-STD-461A Limits
Conducted emission CE 01	LIC 1 bus, 7.2 dB above limit at 8.67 KHz LIC 1 return 10.1 dB above limit at 8.62 KHz 6.4 dB above limit at 8.86 KHz 1.6 dB above limit at 17.3 KHz
Conducted emission CE 03	LIC 1 return, 9 dB above limit at 5 MHz
Conducted susceptibility CS 01	LIC return lines, some degradation at 30 to 40 mv peak-to-peak applied signal
Conducted susceptibility CS 06	No effect noted
Radiated emission RE 02	All modes, 10 MHz 2 dB above limit Communications mode, initial problem at 150 MHz corrected by improved test setup. Multitone mode 180 MHz 22.7 dB above limit 360 MHz 4.3 dB above limit 540 MHz 3.1 dB above limit 720 MHz 1.5 dB above limit
Radiated susceptibility RS 03	Interference threshold 20 dB below limit at various frequencies from 10.5 MHz to 180.0 MHz Initially 40 dB below limit at 10.2 MHz After shielding 20 dB below limit at 10.2 MHz

TABLE 4-8. RADIATED EMISSION IN REGION OF COMSAT RECEIVER FREQUENCY WITH SUBSYSTEM TERMINATED WITH RF LOADS

TWTA Status	Emission Level	
	CW Mode, 20.00 GHz	Multitone Mode, 17.80 GHz
All TWTAs OFF, dBm	-65	<-93*
20 GHz horn antenna ON, dBm	-65	<-93*
20 GHz parabolic antenna ON, dBm	-61	<-93*

*Noise level of receiver -93 dBm.

The most serious problem evidenced in the EMI tests was a significant susceptibility to radiation in the region of 10 MHz. This susceptibility was improved, though not to the point where it would be compliant with MIL-STD-461A, by completely shielding the cable between the RF multiplier unit and the modulator/power amplifier unit. This amount of improvement was considered satisfactory for compatibility with the spacecraft EMI environment.

REFERENCES

4-1. GSFC Document S-320-ATS-2, "Environmental Test Specification for Components and Experiments," ATS-F and G, Revision D, 10 May 197 .

4-2. Hughes Document 3253300-600, "General Test Plan, HS-330," Millimeter Wave Experiment for ATS-F, Revision B, 28 April 1972.

4-3. Hughes Document 3253301-600, "Qualification Test Plan, Electronic Subsystem 3253300-100," Millimeter Wave Experiment, Revision B, 28 April 1972.

4-4. Hughes Document 3253301-601, "Electronic Subsystem Electromagnetic Interference Test Plan," Millimeter Wave Experiment, 16 May 1972.

4-5. Hughes Document 3253301-650, "Long Form Test Procedure," Millimeter Wave Experiment for ATS-F, 27 July 1972.

4-6. Hughes Document 3253301-651, "Short Form Test Procedure," Millimeter Wave Experiment for ATS-F, 27 July 1972.

4-7. Hughes Document 3253310-600, "RF Multiplier Test Plan and Specification 3253310-100," Millimeter Wave Experiment for ATS-F, Revision A, 09 September 1971.

4-8. Hughes Document 3253320-600, "Modulator/Power Amplifier Unit Test Plan and Specification 3253320-100," Millimeter Wave Experiment for ATS-F, 13 September 1971.

4-9. Hughes Document 3253351-600, "Acceptance Test Plan, 20 GHz TWT Amplifier 3253351-100," 27 July 1972.

4-10. Hughes Document TS 3253353-600, "Test Specification, 20 GHz TWT Power Supply, HS-330," 10 May 1971.

4-11. Hughes Document 3253353-601, "Qualification Test Procedure, 20 GHz TWT Power Supply 3253353-100," 20 December 1971.

4-12. Hughes Document 3253361-600, "Acceptance Test Plan, 30 GHz TWT Amplifier 3253361-100," 27 July 1972.

4-13. Hughes Document TS 3253363-600, "Test Specification, 30 GHz TWT Power Supply, HS-330," 10 May 1971.

4-14. Hughes Document 3253363-601, "Qualification Test Procedure, 30 GHz TWT Power Supply 3253363-100," 20 December 1971.

4-15. Hughes Document 3253370-600, "Qualification Test Plan, 20/30 GHz Horn Antennas, HS-330," Revision A, 04 July 1971.

4-16. Hughes Document 3253380-600, "Qualification Test Plan, 20/30 GHz Parabolic Antenna, HS-330," Revision A, 4 July 1971.

4-17. Hughes Document ATP151632, "Acceptance Test Procedure, 268H," Revision C, 21 January 1972.

4-18. Hughes Document QTP151632, "Qualification Test Procedure, 268H," Revision A, 16 March 1971.

4-19. Hughes Document ATP151640, "Acceptance Test Procedure, 254H," Revision A, 8 October 1971.

4-20. Hughes Document QTPB151640, "Qualification Test Procedure, 254H," Revision A, 29 June 1971.

4-21. Hughes Document HS-330-31006, "ATS-F Millimeter Wave Experiment 20/30 GHz Horn Antenna and 20/30 GHz Parabolic Antenna Final Report," January 1972.

4-22. "Hughes Electron Dynamics Division Qualification Test Report, 268H," Serial No. Q3, October 1971.

4-23. "Hughes Electron Dynamics Division Qualification Test Report, 254H," Serial No. Q1, November 1971.

4-24. MIL-STD-462, "Electromagnetic Interference Characteristics, Measurement of," Notice 2.

4-25. MIL-STD-461A, "Electromagnetic Interference Characteristics, Requirements for Equipment," Notice 2.

5. QUALITY ASSURANCE

INTRODUCTION

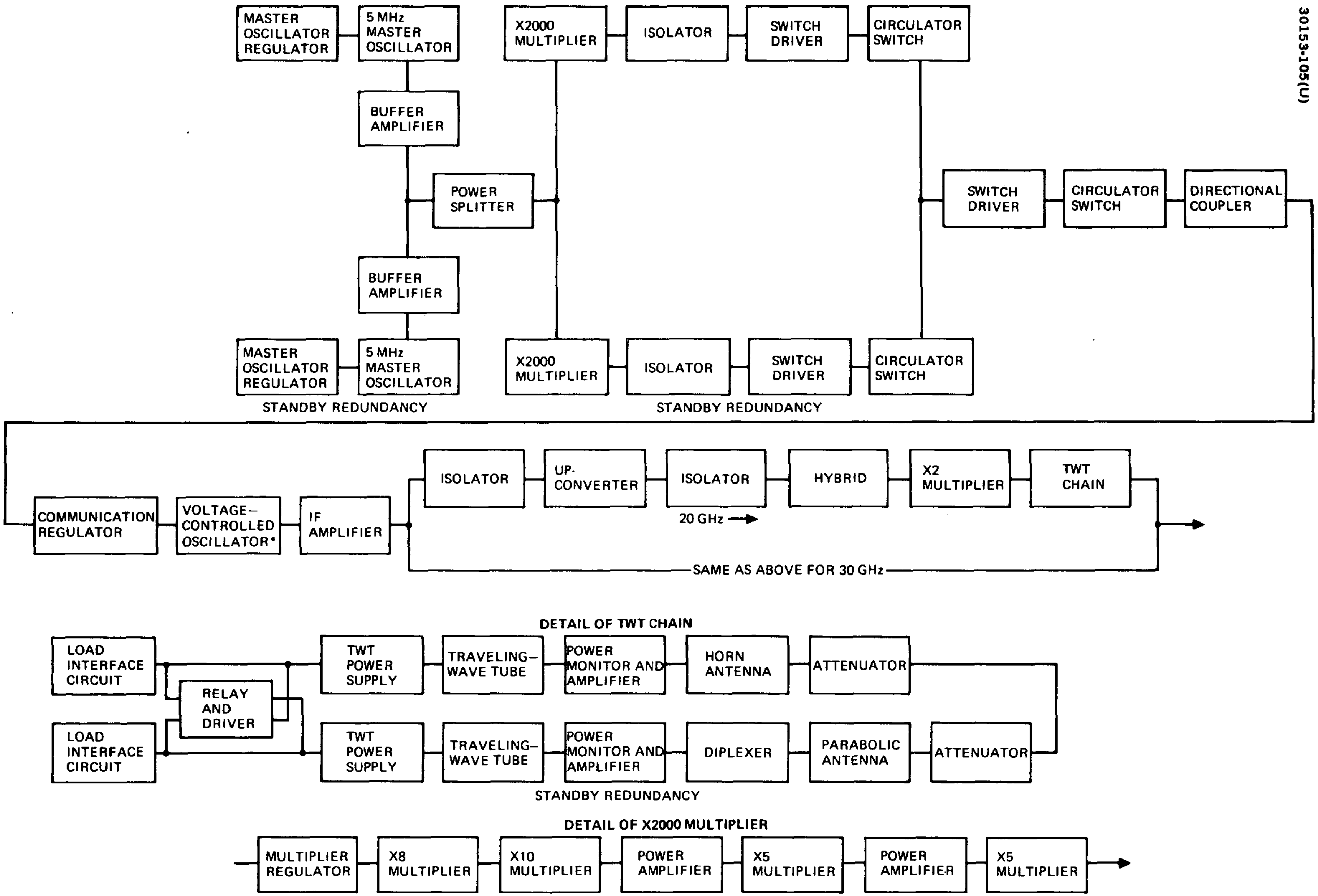
The purpose of this section of the millimeter wave experiment final report is to summarize the important aspects of the quality assurance efforts conducted during the development and production of the experiment. These efforts were performed in accordance with the millimeter wave experiment Quality Program Plan (Reference 5-1) and the millimeter wave experiment Reliability Program Plan (Reference 5-2) submitted to GSFC early in the development phase of the contract. Discussed in the following subsections are experiment reliability, selection of components and materials, and a summary of troubles and failures encountered in the testing of the flight/prototype model.

RELIABILITY

In accordance with the Reliability Program Plan (Reference 5-2), every effort was made to produce a reliable experiment. In the early stages of development the subsystem was modeled, mathematical equations written, and the reliability predictions calculated. A failure mode and effects analysis was also made to delineate single point features. The experiment configuration was reviewed and where necessary, redundancy was added or deleted. The results of both studies were examined in considerable detail and various design changes were made to optimize the reliability at minimum weight and cost.

The subsystem was modeled as shown on the reliability block diagrams of Figures 5-1, 5-2, and 5-3 for the three modes of subsystem operation. Based on these models the reliability of each mode of operation was calculated (Reference 5-3), taking into consideration the temperature and stress of each electronic part. The failure rate of parts in these calculations was the same part failure rate as that used in calculating the reliability of communication satellites. The probability that the experiment will function successfully for 6 months based on 40 hours of operation per week was found to be greater than 0. 99.

The primary life limiting devices in the entire experiment was thought to be the traveling-wave tubes. Each tube has a cathode made of the conventional barium oxide paste. The cathode area has been designed for a life in



*VOLTAGE-CONTROLLED OSCILLATOR USED ONLY FOR BASEBAND CROSS-STRAP

FIGURE 5-1. MILLIMETER WAVE EXPERIMENT RELIABILITY BLOCK DIAGRAM - COMMUNICATION MODE

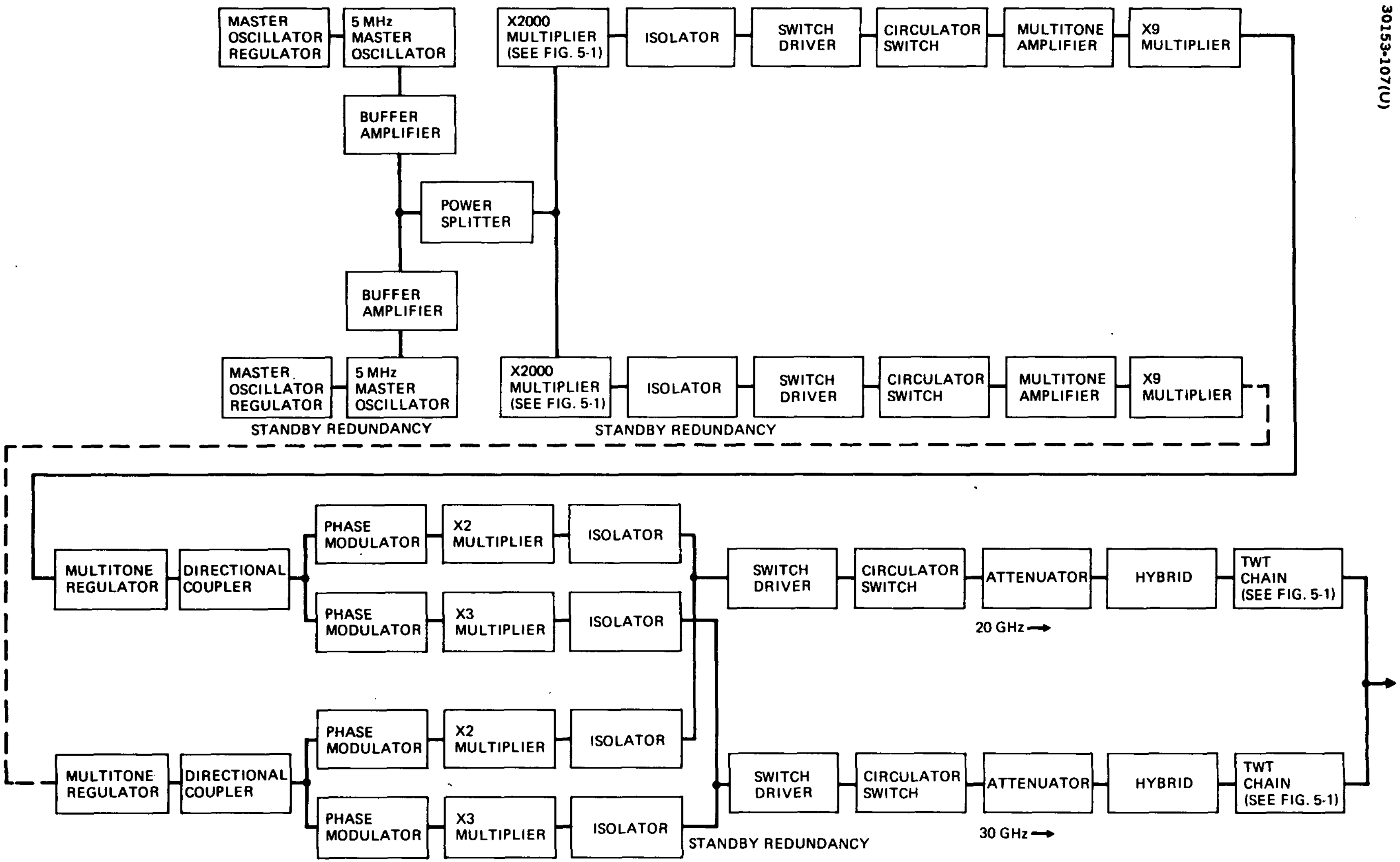


FIGURE 5-2. MILLIMETER WAVE EXPERIMENT RELIABILITY BLOCK DIAGRAM - MULTITONE MODE

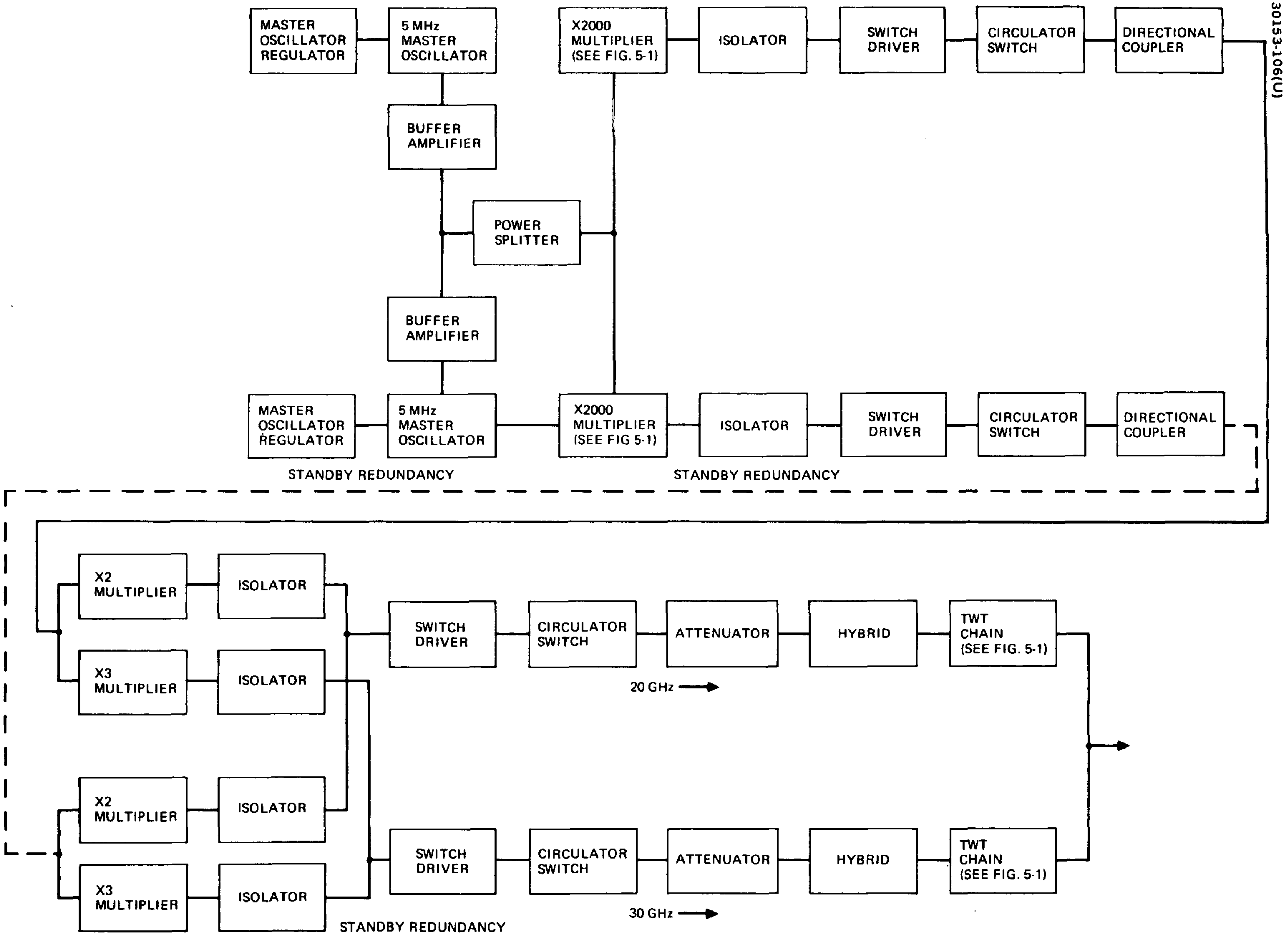


FIGURE 5-3. MILLIMETER WAVE EXPERIMENT RELIABILITY BLOCK DIAGRAM - CONTINUOUS WAVE MODE

excess of 100,000 hours. Since the 6 month requirement is a little over 1000 hours, there is a safety factor of 100. Or looked at in another way, the cathode life time in the TWTs on a 40 hour/week basis is about 50 years.

A failure mode, effect, and criticality analysis was performed (Reference 5-4) to identify the effects of single failures which could cause the experiment to be inoperative. The analysis treated "open" and "short" conditions at the interfaces of the control items in order to be sure that the redundant items would work satisfactorily and would have no adverse effects in the rest of the spacecraft. The number of failures of all kinds which could cause the experiment to go off the air has been reduced to a minimum by careful system design and the use of redundant control items where necessary.

COMPONENTS AND MATERIALS SELECTION

At the beginning of the program a Parts Board was set up consisting of experts drawn from Components and Material, System Engineering, Purchasing, and Product Effectiveness Departments. This Board met at regular intervals to discuss the risks involved in putting specific electronic parts on the approved parts list. All part types on the original list have been used on other space programs and parts added subsequently have been approved for use in the millimeter wave experiment by the Components and Materials Laboratory. Additional parts were added only after a thorough investigation and qualification test had been performed by the Components and Materials Laboratory. The list (Reference 5-5), which now comprises approximately 150 parts, was submitted as parts were added to GSFC for approval. Early in 1971 a new authorized parts list was prepared in two sections. The first section contained those high reliability electronic parts which require traceability and the other section comprised hardware items such as nuts and screws which do not require traceability. Very few additions have been made since that time.

During the course of the program a number of high reliability component specifications were prepared, components were qualified to these specifications where necessary, and flight components were purchased against them for assembling the flight/prototype model of the experiment. Many of the new specifications were for passive microwave parts such as attenuators, flanges, bends, etc., for the 20 and 30 GHz waveguide assemblies since components at these frequencies had not previously been used in spacecraft at Hughes. The more significant new items were five microwave diodes (high reliability part No. 908233, 908234, 908235, 908237, and 908238) and two transistors (Hughes high reliability part No. 908876 and 908877). The microwave diodes were primarily for use at the higher frequencies where no previously qualified parts could be used. Applications included the phase modulators, X2 multipliers, X3 multipliers, upconverters, and power monitors. One of the transistors was a repackaged version of a previously qualified chip, and in this case the new package configuration made the 400 MHz power amplifier vastly easier to design and produce. The second transistor (908877) was the newly available MSC-3003 microwave power transistor which was utilized in the 2 GHz power amplifier. Amplification at 2 GHz to the power level achievable with the MSC-3003 was necessary because of the high power losses in subsequent frequency multiplication and modulation of the signals. Because of a failure of a similar transistor in another program at Hughes, there was serious concern about the use of the MSC-3003 in the millimeter wave experiment. However, an accelerated life test was performed on several transistors from the same lot as the flight parts and the results indicated that there is a life expectancy at least two orders of magnitude greater than the 6 month requirement for the experiment.

In addition to the list of approved parts, a list of materials and processes (Reference 5-5) for use in the experiment was prepared and submitted to GSFC for approval. With two exceptions – materials with excessive or unknown outgassing properties – the list was approved. The first material was the polyurethane foam (from a particular manufacturer) used in low frequency modules. Here an alternate manufacturer's material was recommended by GSFC which was used in all but several very critical applications with a waiver being granted by GSFC for the specific critical applications. The second exception related to the cure cycle specified for CTL-15 paint. Again the GSFC recommended cure cycle was used for all applications except where the higher temperature cure would cause damage inside the modules.

TROUBLE AND FAILURE SUMMARY

In accordance with the Quality Program Plan a system of formal reporting of troubles and failures was carried out. This system, which is invoked during test of major control items and higher levels of assembly, involves the reporting of the failure by the test engineer, analysis and instituting of corrective action by the responsible engineering activity, verification of appropriate repair or rework by quality control, and review and close out by the Failure Review Board. During the course of testing of the experiment a total of 31 trouble and failure reports (TFRs) were generated and processed.

Of the 31 TFRs, 18 were associated with problems occurring in qualification level vibration tests of three units: the parabolic antenna, the RF multiplier, and the modulator power amplifier. A number of the problems were failures in semirigid coax cables or brackets supporting them and these were corrected by rerouting the cables or replacing with flexible coax. More major problems were failures which occurred in the parabolic antenna feed waveguide, modules located on the upper deck of the RF multiplier, and phase modulator modules in the modulator/power amplifier. In each case structural design changes were required and the flight hardware was reworked to the revised designs. After the corrective action had been accomplished for all of the TFRs, the affected units were retested successfully to a somewhat modified qualification level vibration profile, or in the case of the parabolic antenna, to the full qualification level.

Three of the TFRs were related to coax connectors and these were due to mishandling or assembly workmanship deficiencies. In each case the connector was replaced and successful test of the experiment was completed.

Five of the TFRs applied to failures in TWTAs, three in the power supplies, and two in the TWTs themselves. One of the power supply failures occurred in vibration and this was traced to a wiring workmanship defect. The other four were high voltage breakdowns which occurred during operation in a vacuum environment. One of the four resulted from broken strands inside a high voltage wire just at the point where the wire exited from the TWT package. It is not certain how the strands became broken, but corrective action was taken to prevent excessive flexing of the lead at this point. The remaining three voltage breakdown problems were more fundamental.

In each case the high voltage breakdown was determined to be within the encapsulated region of the high voltage system. The encapsulant was very carefully removed in steps to locate the fault area, the faults were examined microscopically to determine the characteristics, and other tests were performed to establish the probable cause. The faults were found to exist at voids in the encapsulated system, either in a crack in the encapsulant itself or in a separation between the encapsulant and one of the items to which it should have adhered. The crack or separation became a problem when atmospheric pressure was removed from the exterior of the encapsulated system (vacuum environment) and the crack became a gas filled void.

The cause of the faults cannot be determined with absolute certainty. However, the evidence points very strongly to two causes and probably in a combination. The first is the possibility of improper or incomplete application of the primer to the components before encapsulating. It is mandatory that the primer be applied to all component surfaces since the solithane will not adhere well to the components directly. The second relates to the thermal properties of the solithane which has a very high coefficient of thermal expansion in comparison to components such as the high voltage transformer and furthermore becomes more and more brittle as the temperature decreases. The differential thermal expansion causes very high mechanical stresses to occur in the solithane at and near the bond joint to components. The bond joint, if weak because of primer deficiency, can then shear or actual cracks can develop and propagate in the solithane. The larger the mass of solithane in any one area, the more severe the problem becomes.

Four corrective actions were instituted to reduce the probability of recurrence of high voltage faults. First, a more careful procedure was implemented for application and inspection of the primer. In the case of the power supply this was accompanied by a revised sequence of assembling and encapsulating the transformers to permit the better inspection. Second, the volume of solithane in one fairly large area in the power supply was reduced by a change in the mold. Third, an epoxy glass strengthening web was added in this same area in the power supply. And finally, a limitation of -5°C was placed on the low temperature exposure and no temperature testing of the complete experiment was done below this limit, although each of the power supplies and the TWTs were operated one time at -10°C to provide assurance that there would be no problems at -5°C.

The remaining five TFRs related to various troubles. Two were generated because improper acceptance limits had been selected in test procedures. One was due to a noisy Johanson capacitor, a perennial problem if the capacitor has been adjusted too many times. One was a transistor failure which was analyzed to have resulted from an overvoltage stress, probably due to a test power supply. The last was due to spurious commands introduced by transient phenomena in an environmental chamber.

REFERENCES

5-1. Quality Assurance Program Plan, Millimeter Wave Experiment for ATS-F, HS-330-3002B, dated July 1971.

5-2. Reliability Program Plan, Millimeter Wave Experiment for ATS-F, HS-330-3001, dated 21 August 1970.

5-3. HS-330 Millimeter Wave Experiment Final Reliability Prediction Report, 271221/76, dated 26 April 1971.

5-4. HS-330 Millimeter Wave Experiment Failure Mode Effects and Criticality Analysis Report, 271221/49, dated 15 April 1971.

5-5. Materials and Processes List and Authorized Parts List for HS-330, HS-330-3098, dated 13 October 1971.

6. BENCH TEST EQUIPMENT

GENERAL DESCRIPTION

A set of special test equipment was designed and built for testing the millimeter wave experiment. The equipment, designated as bench test equipment (BTE), consists of a combination of commercial test equipment and special items designed and fabricated by Hughes. The purpose of the bench test equipment was to facilitate testing during formal performance testing and environmental testing of the flight/prototype model of the experiment at Hughes, during incoming testing of the flight/prototype model at the spacecraft contractor's facility, and during long form test of the experiment on the ATS-F spacecraft.

The bench test equipment consists of a three bay rack of test equipment, a microwave test assembly, two radiation hat couplers to be attached to the spacecraft over the experiment antennas, and miscellaneous cables and waveguides. A photograph of the three bay rack is shown in Figure 6-1. The equipment may be connected in various ways depending upon the objectives of the particular test. An overall block diagram of the BTE when used for testing the electronic subsystem of the experiment is shown in Figure 6-2. A block diagram of the bench test equipment when used for performing the long form test on the spacecraft is shown in Figure 6-3. In this latter case the spacecraft telemetry and command subsystems are used for control and for telemetry monitoring of the experiment.

More detail on the dc power functions, command decoder simulator panel, telemetry test panel, and RF measurement functions are described in subsequent paragraphs.

DC POWER CONTROL AND MONITORING

Basic control of the dc power applied to the experiment is accomplished by the load interface circuit control panel. This panel, shown in Figure 6-4, controls the voltage forms from two commercial power supplies and applies the power to the two dc power inputs of the experiment. No attempt was made to precisely simulate the spacecraft load interface circuit (LIC) in the panel, but rather to provide laboratory controlled input power conditions. Gross measurements of the voltage and current in each of the two LIC lines are provided by meters on the panel. Precise measurements

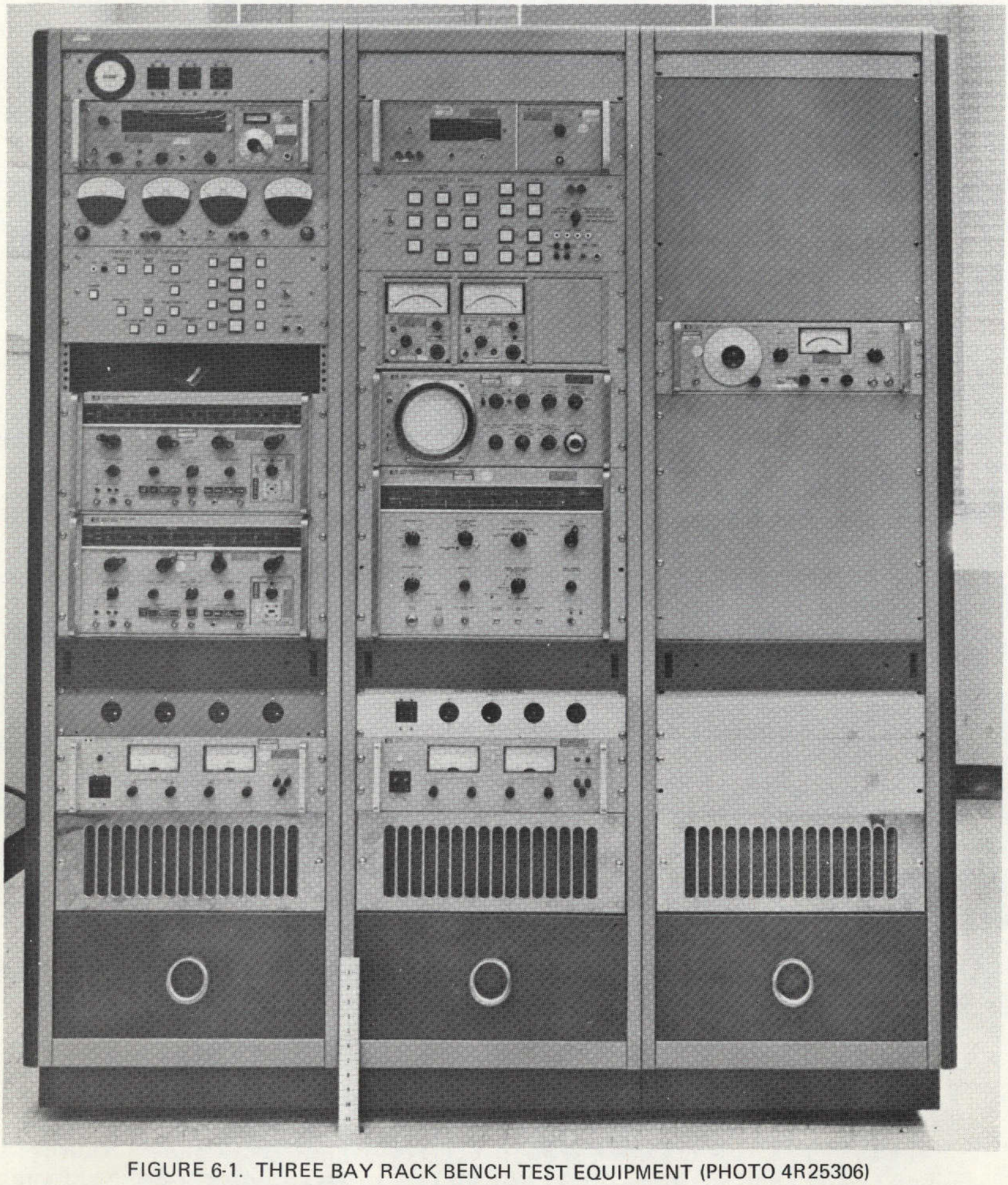


FIGURE 6-1. THREE BAY RACK BENCH TEST EQUIPMENT (PHOTO 4R25306)

are accomplished by attaching a digital voltmeter and a precision ammeter (both included in the bench test equipment) to appropriate jacks on the face of the panel. The panel contains provisions for preventing application of reverse voltages and by means of a "crowbar" protective circuit, for preventing under- and overvoltage conditions.

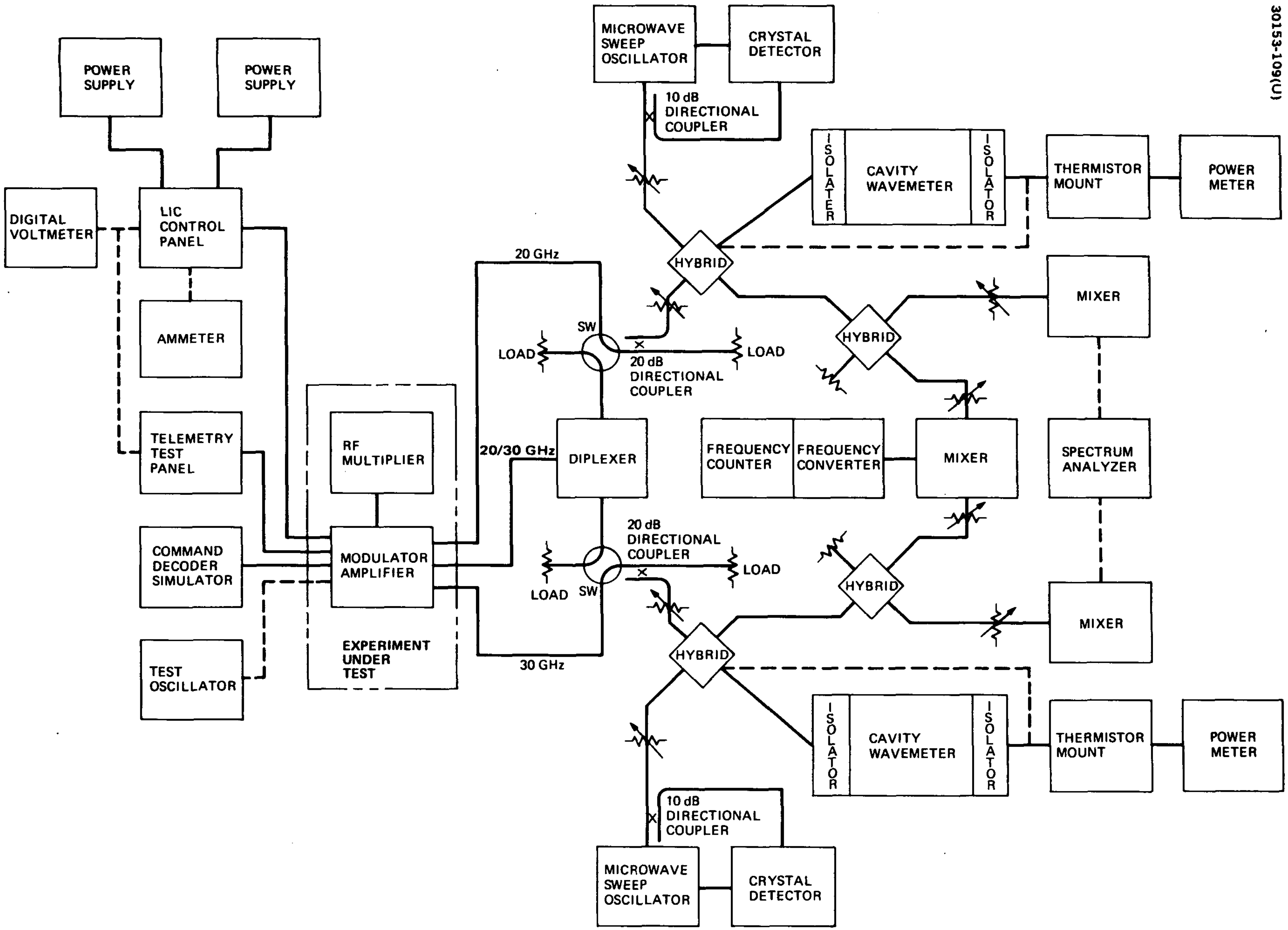


FIGURE 6-2. BENCH TEST EQUIPMENT BLOCK DIAGRAM - LABORATORY TEST OF ELECTRONIC SUBSYSTEM

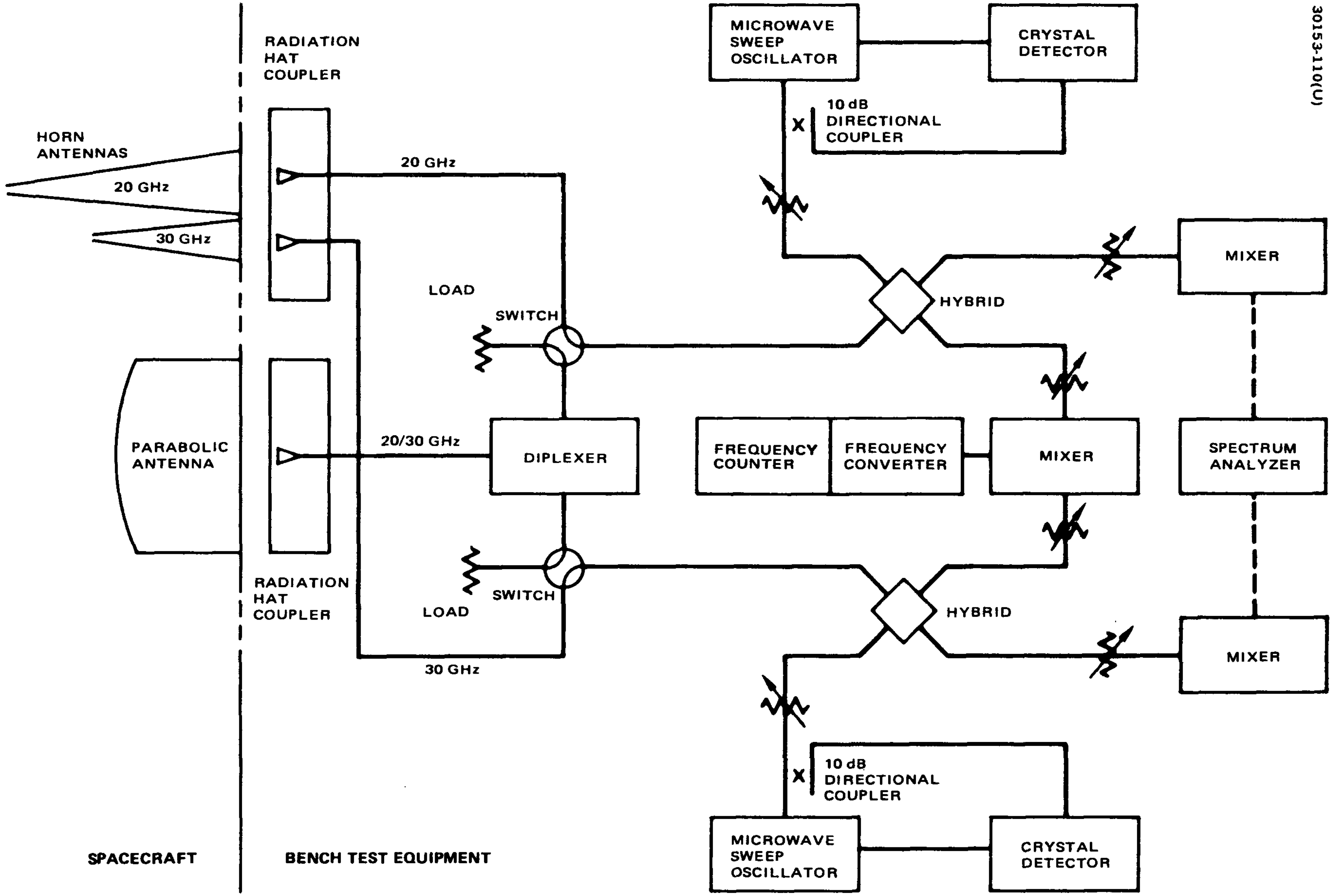


FIGURE 6-3. BENCH TEST EQUIPMENT BLOCK DIAGRAM—TEST OF EXPERIMENT ON SPACECRAFT

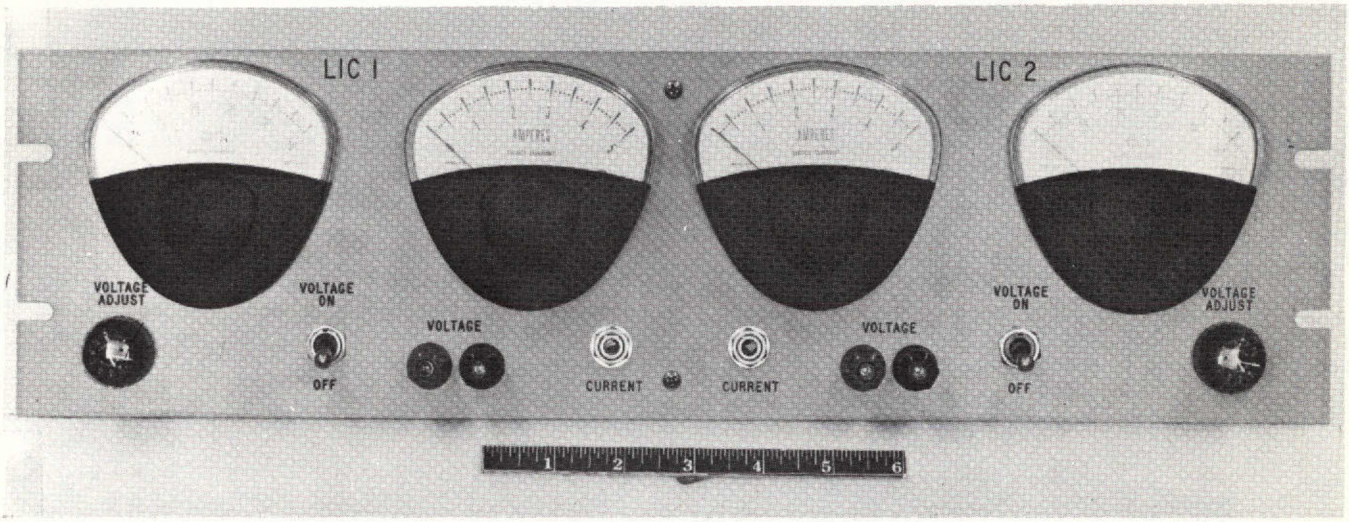


FIGURE 6-4. LIC CONTROL PANEL (PHOTO 4R22834)

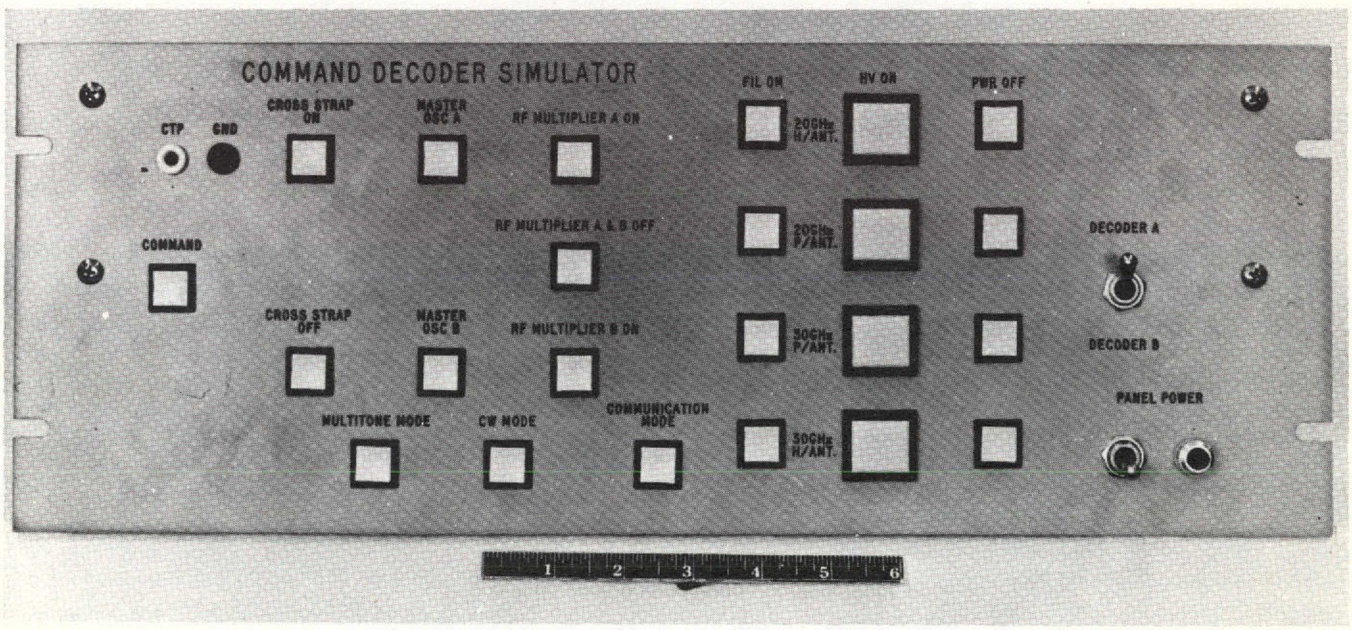


FIGURE 6-5. COMMAND DECODER SIMULATOR PANEL (PHOTO 4R22840)

COMMAND DECODER SIMULATOR PANEL

The command decoder simulator panel, shown in Figure 6-5, serves the purpose of simulating the spacecraft command decoder functions. It provides for manual issuance of commands to the experiment for turning on and off the various experiment functions to arrive at all desired functional configurations and operating modes. It is connected via a cable to the command interface connector of the experiment and by means of a rotary switch on the panel, it can direct commands through either the lines corresponding to decoder A or those corresponding to decoder B.

Commands to the experiment are applied by establishing continuity from the command pulse generator to a particular command line by depressing and holding down the designated command pushbutton switch, and then momentarily depressing the command execute switch. A positive 5 volt, 50 millisecond pulse from the command pulse generator is then applied to the command line. Thus, for example, by depressing the master oscillator A switch and momentarily depressing the command switch, a command pulse will be applied to the master oscillator A regulator, turning it on. The next command is then applied in a similar manner for the next desired command action. An attempt was made to simulate as closely as possible the spacecraft decoder interface circuit by the design of the command pulse generator.

In order to ensure the proper time delay between turning on TWTA filaments and applying TWTA high voltage, the panel incorporates four 90 second timers, one for each TWTA. Application of the filament ON command to a given TWTA initiates the timing action. Upon expiration of the 90 second warmup interval, the light indicator in the high voltage ON switch on the panel will light up signifying that the high voltage ON command can be issued. The light indicator remains lighted until the high voltage ON command is issued.

TELEMETRY TEST PANEL

The telemetry test panel, shown in Figure 6-6, serves two basic functions. First, it provides for measurement of all of the telemetry output voltages from the experiment, and second, it displays the status of the experiment by utilizing the telemetry voltages to control corresponding light indicators on the panel. The panel is connected to the two telemetry interface connectors of the experiment by two cables and selection of telemetry encoder A or encoder B lines is accomplished by a toggle switch on the panel.

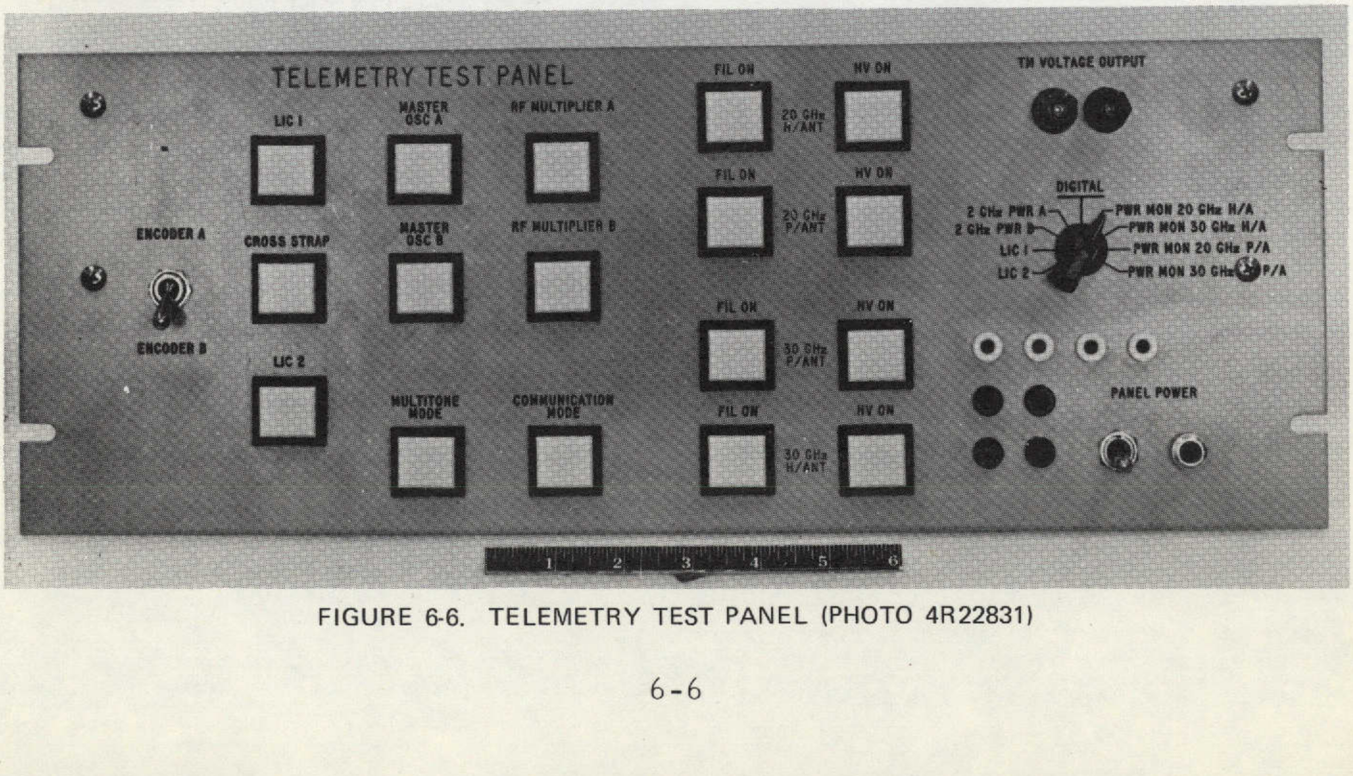


FIGURE 6-6. TELEMETRY TEST PANEL (PHOTO 4R22831)

For status display only the digital (or bilevel) telemetry signals and the LIC analog telemetry signals are used. If the telemetry signal is 0 volt (logic zero state) the status lights remain off, and if the telemetry voltage is above approximately 3 volts the status light goes on. Precise measurements of the digital telemetry voltages are made by connecting a digital voltmeter (included in the bench test equipment) to the telemetry voltage output jacks on the panel, turning the selector switch to the digital position, and depressing the combination light indicator/switch for the desired channel.

Except for temperature monitor channels, the measurements of analog telemetry voltage are also made through the telemetry voltage output jacks. In this case immediate readings are available when the selector switch is rotated to the desired telemetry channel. The temperature monitor channel voltages are available on separate jacks on the panel.

RF MEASUREMENTS

RF measurements made on the experiment require various configurations of test instruments and microwave equipment in the bench test equipment. The four most important classes of measurements are described below. The configuration of the equipment for each can be determined from the narrative description and by referring to the block diagrams of Figures 6-2 and 6-3.

Total RF Output Power

The waveguide test setup for this measurement consists of a 20 dB directional coupler at each of the 20 and 30 GHz horn antenna and parabolic antenna ports. The coupler direct output is terminated with a load. The coupled output arm is connected to a precision variable attenuator followed by an isolator and a thermistor mount. A power meter connected to the thermistor mount will read the total power at the particular output port, less the insertion loss of the waveguide test setup.

Individual Line Power of Multitone Mode

An isolator followed by a transmission type cavity wavemeter is inserted after the precision variable attenuator of the above waveguide test setup. A power meter connected to the thermistor mount will read the power in the individual lines of the multitone mode, less the insertion loss of the waveguide test setup. The individual line can be identified by the frequency scale on the transmission type cavity wavemeter.

Spectrum Analyzer Display of Multitone Spectrum

One of the two input ports of a 3 dB hybrid is connected to the output port of the precision variable attenuator of the above waveguide test setup. A 10 dB directional coupler is connected to the RF output port of a sweep oscillator. A crystal detector is connected to the coupled output arm of the coupler to provide an automatic leveling control (ALC) signal to the sweeper.

The direct output of the coupler is attenuated with a nonprecision variable attenuator and then connected to the second input port of the hybrid. An isolator followed by a thermistor mount is connected to one of the two output ports of the hybrid. A power meter connected to the thermistor mount will read the approximate power in sequence from the sweeper (LO) and from the 20 or 30 GHz, horn antenna or parabolic antenna port at the other output port of the hybrid, which is connected to the spectrum analyzer (via a transition and mixer). The multitone spectrum of the particular output port is displayed on the spectrum analyzer.

Frequency Difference of 20 and 30 GHz Outputs

The direct output arm of the 10 dB direction coupler is connected to the second output port of the 20 GHz 3 dB hybrid of the 20 GHz version of the waveguide test setup as described for the spectrum analyzer display above. A WR28 to WR42 transition followed by the coupled output arm of the coupler is connected to the second output port of the 30 GHz 3 dB hybrid of the 30 GHz version of the waveguide test setup as described for the spectrum analyzer display above. The first output port of each of the 20 and 30 GHz 3 dB hybrids is terminated with an isolator and thermistor mount. The input port of the 10 dB directional coupler is connected to the mixer. The 10 GHz difference frequency from the mixer is applied to the frequency converter and measured on the frequency counter.

7. NEW TECHNOLOGY

During the development portion of the contract, three items of new technology were identified and reported in accordance with the New Technology Clause of the contract.

The first of these was the microwave diode pure phase modulator. It makes use of the principle that the reflected microwave signal and the transmitted microwave signal at a varactor diode mounted in a waveguide are shifted in phase by an equal, but opposite amount. By mounting the diode in a bridge circuit consisting of a power splitter, two circulators, and a power combiner, the total RF energy is recovered with little loss, but shifted in phase by an amount determined by the modulating voltage on the varactor diode.

The second item was also a microwave phase modulator, very similar in principle to that described above. It differed only in that it was a single ended device rather than a bridge circuit.

The third device was a microwave amplitude equalizer which made use of a series of tuned absorption cavities discretely positioned along a waveguide. The device permitted selective adjustment of specific spectral components of the signal by varying the coupling of the tuned absorption cavities.

Of the three items identified, only the second described above was actually used in the final experiment design.